Gray Triggerfish Fishery-Independent Indices of Abundance in US South Atlantic Waters Based on a Chevron Trap Survey

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Final index is found in the addendum.

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Abstract

Fishery-independent measures of catch and effort with standard gear types and deployment strategies are valuable for monitoring the status of stocks, interpreting fisheries landings data, performing stock assessments, and developing regulations for managing fish resources. This report presents a summary of the fishery-independent monitoring of Gray Triggerfish in the US South Atlantic region and includes data from the three monitoring programs (MARMAP, SEAMAP-SA, and SEFIS, known collectively as SERFS). Specifically, it presents annual nominal catch per unit effort (CPUE) of Gray Triggerfish from chevron traps from 1990 to 2013. Also included are annual CPUE estimates for chevron trap catches from 1990 to 2013 standardized by zero-inflated negative binomial models (ZINB). The standardized models account for the effects of potential covariates that may affect sampling or abundance, other than year of capture, on annual CPUE estimates. Length and age compositions for Gray Triggerfish collected by chevron trap also are included to describe gear selectivity. The ZINB model fit best to observed catches of Gray Triggerfish. Standardized annual CPUE estimates normalized to the series average indicates that CPUE initially increased through the late 1990s before subsequently decreasing through the mid- to late-2000s. Since approximately 2006, CPUE in the region has been increasing.

Introduction

Fishery-independent measures of catch and effort with standard gear types and deployment strategies are valuable for monitoring the status of stocks, interpreting fisheries landings data, performing stock assessments, and developing regulations for managing fish resources. Inevitably, tighter management regulations result in fishery-dependent catches reflecting the demographics of a restricted subset of the population, affecting the utility of fishery-dependent data when assessing the current status of the stock. When fisheries are highly regulated, fishery-independent surveys are often the only method available to adequately characterize population size, age and length compositions, and reproductive parameter distributions, all of which are needed to assess the status of stocks. The Marine Resources Monitoring, Assessment and Prediction (MARMAP) program has conducted fishery-independent research on the continental shelf and shelf edge between Cape Hatteras, North Carolina, and St. Lucie, Florida, for over 40 years to provide information for reliable stock assessments and evaluation of management plans. Housed at the Marine Resources Research Institute (MRRI) at the South Carolina Department of Natural Resources (SCDNR), the overall mission of the MARMAP program has been to determine the distributions, relative abundances, and critical habitats of economically and ecologically important fishes of the SAB, and to relate these features to environmental factors and exploitation activities.

Although the MARMAP program has used various gear types and methods of deployment since its inception, the program has strived to use consistent gears and sampling methodologies throughout extended time periods to allow for analyses of long-term changes in relative abundance, length frequencies, and other information. As such, the MARMAP program primarily has used a standard sampling methodology with chevron traps for monitoring purposes on known live-bottom habitats since 1990. The focus of this report is on developing an annual catch per unit effort (CPUE) or abundance index for Gray Triggerfish (*Balistes capriscus*) based on chevron trap catches from 1990 to 2013.

Until recently, the MARMAP program was the only long-term fishery-independent program that collected the data necessary to develop indices of relative abundance for species in the South Atlantic Fisheries Management Council's (SAFMC) snapper-grouper species complex. In 2008, with a first field season occurring in 2009, the Southeast Area Monitoring and Assessment Program's South Atlantic component (SEAMAP-SA) provided funding to complement MARMAP efforts. A particular goal of the SEAMAP-SA Reef Fish complement is to assist with the expansion of the geographical sampling coverage of the current fishery-independent surveys, focusing on either shallow or deep potential live-bottom areas. In addition, the SEAMAP-SA complement funding allowed for expanded sampling in marine protected areas (MPAs).

Beginning in 2010, NOAA Fisheries made funding available to create the Southeast Fisheries Independent Survey (SEFIS) program housed at the Southeast Fisheries Science Center (SEFSC) laboratory in Beaufort, NC. This fishery-independent survey was designed to further complement the historical MARMAP/SEAMAP-SA reef fish monitoring efforts, again aimed at extending the geographical range of the surveys. SEFIS activities were coordinated closely with MARMAP/SEAMAP-SA staff, which trained SEFIS personnel and have participated in SEFIS monitoring cruises. SEFIS uses gear and methodologies identical to MARMAP/SEAMAP-SA to maintain the integrity of the long-term data set. In 2011, for logistical and cost savings reasons and since all programs were using identical sampling methods, it was decided that SEFIS vessels would concentrate sampling efforts in waters off Georgia and Florida, while MARMAP/SEAMAP-SA vessels would concentrate efforts off South Carolina and North Carolina. Given the close coordination and consistent sampling methodology used by each of the fishery-independent sampling programs, it is possible to combine catch, effort, and length data collected by each program for chevron traps for the analyses presented in this report (see **Error! Reference source not found.** for gear deployment summary). The combined efforts of MARMAP, SEAMAP-SA Reef Fish Complement, and SEFIS to conduct fishery-independent reef fish monitoring in the US South Atlantic region are now referred to as the Southeast Reef Fish Survey (SERFS).

Objective

This report presents a summary of the fishery-independent monitoring of Gray Triggerfish in the US South Atlantic region and includes data from the three monitoring programs (MARMAP, SEAMAP-SA, and SEFIS, known collectively as SERFS). Specifically, it presents annual nominal catch per unit effort (CPUE) of Gray Triggerfish from chevron traps from 1990 to 2013. Also included are annual CPUE estimates for chevron trap catches from 1990 to 2013 standardized by a zero-inflated negative binomial model (ZINB). The standardized model accounts for the effects of potential covariates that may affect sampling or abundance, other than year of capture, on annual CPUE estimates. Data presented in this report are based on the combined SERFS database accessed on June 20, 2014, and include data collected through the 2013 sampling season.

Methods

Survey Design and Gear

The standard SERFS sampling area includes waters of the continental shelf and shelf edge between Cape Hatteras, NC, and St. Lucie Inlet, FL, although over the years the majority of sampling has occurred south of Cape Lookout, NC (Figure 1). Throughout this range, we sample stations established on confirmed live bottom (monitoring) from May through September each year, though cruises have occurred prior to and after these months in some years. Traps deployed on suspected live bottom in a given year (reconnaissance) are evaluated based on catch and video or photographic evidence of bottom type for inclusion in the sampling frame the next year.

MARMAP began using chevron traps in 1988 after a commercial fisherman introduced the use of this trap design in the US South Atlantic region (Collins 1990). Subsequently, in 1988 and 1989, chevron traps were used simultaneously with blackfish and Florida Antillean traps to compare the efficiency of the three different trap designs at capturing reef fishes on live-/hard-bottom habitats (Collins 1990). Results indicated that the chevron trap was most effective overall for species of commercial and recreational interest in terms of both total weight and numbers of individuals captured (Collins 1990). Based on these results, the MARMAP program has used chevron traps for reef fish monitoring purposes in the US South Atlantic since 1990, using this single gear to replace both blackfish and Florida Antillean traps. Currently, all three fishery-independent monitoring programs composing SERFS continue to utilize the chevron trap as their primary monitoring gear.

Each year, stations are selected randomly from known live-/hard-bottom stations identified for monitoring via fish traps (low to moderate relief) in that year (currently ~ 3,500 stations are available). Stations are selected randomly in a manner such that no station selected in a given year is closer than 200 m to any other selected station, though the minimum difference typically is closer to 400 m. Chevron traps have been deployed at depths ranging from 13 to 218 m, although the depth of usage generally is less than 100 m. The vast majority of the deeper deployments occurred in 1997.

The chevron trap time series has been continuous from 1990 to present, although the distribution and extent of sampling has changed over time. The spatial coverage of the survey has expanded over the time series as we have added stations and sampling effort in the northern and southern ends of the survey. Figure 1 shows the extent of the survey for all sampling years included in this report and the locations of Red Snapper catches and Table 1 shows changes in the survey with regards to some environmental variables over all years included in this report.

Chevron traps are arrowhead shaped, with a total interior volume of 0.91 m^3 (Figure 2, Collins 1990). Each trap is constructed of 35 x 35 mm square mesh plastic-coated wire (MARMAP 2009). Each trap possesses a single entrance funnel ("horse neck") and release panel to remove the catch (Collins 1990; MARMAP 2009). Prior to deployment each chevron trap is baited with a combination of whole or cut clupeids (*Brevoortia* or *Alosa* spp., family Clupeidae), with *Brevoortia* spp. most often used. Four whole clupeids on each of four stringers are suspended within the trap and approximately 8 clupeids, with their abdomen sliced open, are placed loose in the trap (Collins 1990; MARMAP 2009). An individual trap is attached to an appropriate length of 8 mm (5/16 in) polypropylene line buoyed to the surface using a polyball buoy. We attach a 10 m trailer line to this polyball buoy, with the end of the trailer line clipped to a Hi-Flyer buoy or another polyball. Generally traps are deployed in sets of six when a sufficient number of stations are available in a given area (MARMAP 2009). Traps are retrieved in chronological order of deployment, using a hydraulic pot hauler, after an approximately 90-minute soak time.

Oceanographic Data

While traps are soaking, oceanographic variables (mainly temperature and salinity) are determined using a CTD. Bottom temperature (°C) as used in this report is defined as the temperature of the deepest recording within 5 m of the bottom.

Data and Treatment

Data and Nominal CPUE Estimation

Data available for use in CPUE estimation for each trap (deployment) included a unique collection number, date of deployment, soak time, latitude, longitude, bottom depth, catch code, number of Red Snapper captured, aggregate weight of Red Snapper captured, and bottom temperature, among other variables. We used numbers, instead of weight, of Red Snapper for all analyses. Estimates of CPUE, or relative abundance, are given as the number of Red Snapper caught per trap.

Prior to modeling, a subset of the available SERFS trap data was selected for CPUE estimation based on several criteria:

1) Deployments made via SERFS with a project ID of P05 (MARMAP fishery-independent samples), T59 (SEAMAP-SA Reef Fish Complement fishery-independent samples), and T60 (SEFIS fishery-independent samples)
2) Deployments with catch codes of 0 (no catch), 1 (catch with finfish), 2 (catch without finfish), 9 (recon trap deployment), 90 (recon trap deployment with no catch), 91 (recon trap deployment with finfish), and 92 (recon trap deployment without finfish catch)
3) Deployments with station codes of “Random” (randomly-selected live-bottom station), “NonRandom” (non-randomly sampled live-bottom station (a.k.a. haphazard sample)), “ReconConv” (reconnaissance deployments that were subsequently converted into live-bottom stations), and “Is Null” (traps for which there is no station code value – the use of station codes is fairly new since 2010. Historically we used only the catch ID to indicate randomly-selected stations)
4) Deployments with Gear ID equal to 324 (chevron traps)
5) Deployments with Data Source not equal to “Tag-MARMAP”
    a. “Tag-MARMAP” represents special historic MARMAP cruises that were used to tag various species of fish. Because standard sampling procedures were not used (e.g. not all fish were measured for length frequency) these samples are excluded from CPUE development
6) Deployments at depths between 10 and 94 m

    a. Represents the depth range at which 100% of Gray Triggerfish were collected by any gear used in the SERFS (Ballenger et al. 2012b)
    b. Given previous constraints, this removes 25 traps deployed at <10 m or >94 m of depth and 2 traps for which we are missing depth data
7) Soak times outside of a window between 45 and 150 minutes, which generally indicates deviations from standard protocols
    a. Note, SERFS targets a soak time of 90 minutes for all chevron trap deployments
    b. Removes an additional 193 traps with unusually long or short soak times
8) Deployments made since 1990
    a. Removes an additional 178 traps sampled in 1988 and 1989

Zero-Inflated Model CPUE Standardization

CPUE was standardized among years using a zero-inflated count model. Such a treatment of the data was suggested at the SEDAR 32 data workshop due to the poor fit of the lognormal error distribution for the positive component of the delta-GLM model to the observed data (see Ballenger et al. 2013, Figure 9). Investigation of this technique to model CPUE data also was suggested during the Fishery-Independent Survey Independent Review for the South Atlantic (SEFSC 2012). As is the case with many ecological count data sets (Zuur et al. 2009), the observed CPUE data appeared to be zero-inflated based on preliminary analyses (Figure 3), suggesting the appropriateness of zero-inflated count data models.

Briefly, we provide some background information regarding zero-inflated count data models. For a more complete discussion, see Chapter 11 in Zuur et al. (2009). Zeileis et al. (2008) provides a nice overview and comparison of Poisson, negative binomial, and zero-inflated models in R. Some textbooks devoting sections to the discussion of zero-inflated models include Cameron and Trivedi (1998), Hardin and Hilbe (2007), or Hilbe (2007).

The concept of zero inflation derives from the observation that in many ecological, economic and social studies there are far more zeros in count data than what would be expected for a Poisson or negative binomial distribution. As such, zero inflation means that we have far more zeros than we would expect. Ignoring zero inflation when it exists can have two major consequences, namely the estimated parameters and standard errors may be biased and the excessive number of zeros can cause overdispersion (Zuur et al. 2009).

Zeros due to design and observer errors are called false zeros or false negatives while structural and “animal” zeros are known as positive zeros, true zeros, or true negatives (Zuur et al. 2009). To address these different sources of zeros, two distinctive classes of zero-inflated models have been developed, two-part (hurdle) and mixture models, with the difference between the two classes arising due to differences in how they deal with zeros. Two-part models do not discriminate between the four different types of zeros and simply treat a zero as a zero whereas mixture models account for the type of zero.

Mixture models (zero-inflated Poisson (ZIP) and zero-inflated negative binomial (ZINB)) treat zeros via two different processes: the binomial process and the count process (Zuur et al. 2009). A binomial generalized linear model is used to model the probability of measuring a zero (known as the zero-inflation model) while the count process is modeled by a Poisson or negative binomial GLM (known as the count model). As such, the fundamental difference between hurdle and mixture models is that the count process can produce zeros in mixture models but not in hurdle models (Zuur et al. 2009). In such a setup, the zeros resulting from the count process model represent true zeros, while the binomial GLM models the probability of measuring a false zero versus all other types of data (counts and true zeros; Zuur et al. 2009). In short, the probability functions of a ZINB are:

$$f(y_i = 0) = \pi_i + (1 - \pi_i) * \left(\frac{k}{\mu_i + k}\right)^k$$

$$f(Y_i = y_i | y_i > 0) = (1 - \pi_i) * \frac{\Gamma(y_i + k)}{\Gamma(k) * \Gamma(y_i + 1)} * \left(\frac{k}{\mu_i + k}\right)^k * \left(1 - \frac{k}{\mu_i + k}\right)^k$$

for the binomial component and the non-zero component, respectively. In ZINB, the expected mean and variance are slightly different due to the definition of the probability functions. The mean and variance of a ZINB are:

$$\mathrm{E}(Y_i) = \mu_i * (1 - \pi_i)$$

$$\mathrm{var}(Y_i) = (1 - \pi_i) * \left(\mu_i + \frac{\mu_i^2}{k}\right) + \mu_i^2 * \left(\pi_i^2 + \pi_i\right).$$

If the probability of false zeros is 0, the mean and variance of the negative binomial GLM are equal.

In the development of the ZINB CPUE model for Gray Triggerfish, we modeled CPUE as catch per trap, compared to the traditional method of calculating catch per trap per hour. We included soak time as an offset term instead of creating a catch rate by dividing the catch per trap by the soak time or sample duration. By defining this offset variable we adjust for the amount of opportunity for the gear to capture a fish (e.g. a deployment with a soak time of 120 minutes has twice the opportunity of a deployment with a soak time of 60 minutes).

ZINB models can account for effects of different covariates on observed counts. The same or different covariates can be included in the zero-inflation sub-model and count sub-model. In initial investigations we considered the following covariates in addition to year:

- Depth – continuous variable
- Bottom temperature – continuous variable
- Longitude – continuous variable
- Latitude – continuous variable
- Day of Year (DOY) – continuous variable

Other covariates in the data set that could have been considered included bottom salinity, month, season, dissolved oxygen concentration, chlorophyll-A concentration, nitrite (NO_2) concentration, nitrate (NO_3) concentration, and phosphate (PO_4) concentration. We didn't consider bottom salinity as a potential covariate due to its general lack of variability in oceanic waters and preliminary investigations suggesting there was little relationship between Gray Triggerfish CPUE and bottom salinity. We didn't consider month or season as a covariate as each is correlated to a high degree with our included covariate DOY. Given DOY gives more temporal resolution, the assumption was made that it would provide greater power in standardizing Gray Triggerfish CPUE with regards to within year DOY sampling differences. Finally, we didn't consider the last five potential covariates due to missing values on a large number of trap sets for these variables, primarily due to the lack of equipment to collect these variables historically.

Prior to inclusion of the considered covariates in the full model, we used preliminary analyses to investigate the possibility of collinearity between any of the variables. A pairs plot of continuous covariates revealed high correlation between latitude and longitude (due to the shape of the survey region), and moderate correlation between bottom temperature and depth and bottom temperature and DOY (Figure 4). Variance inflation factor (VIF) estimates for all considered covariates were all <2 (Table 2).

Box plots of the covariates (depth, latitude, bottom temperature, and DOY) among years showed no obvious strong collinearity (Figure 5). With regards to sampling depth, sampling throughout the entire period appeared fairly homogenous, with the possible exception of 1992. With regards to latitude there is some evidence that from 1990-1992 we sampled more northern waters, followed by a fairly homogenous sampling from 1993-2009. Most notable is the expansion in 2010, which corresponds to the first sampling season including SEFIS. Since 2010 the median latitude of sampling has shifted south with an overall broader range of sampling. 1999 was slightly anomalous in that the latitude distribution is restricted compared to surrounding years, with it being more similar to the early years of the survey. For bottom temperature, there is evidence that 2003 (and to a lesser degree 2004) was an exceptionally cold year for bottom temperatures at our sampling locations and times. Conversely, bottom temperatures were warmer than average in 1991 and 1995. Finally, for DOY there does seem to be more year to year variability in days sampled. This is to be expected given the nature of the survey and weather constraints. Most notably, sampling appeared to occur earlier than average in 1990 and 1992 and later than average in 1991 and 2010. Also, sampling in 1999 was restricted temporally compared to other years.

Due to the desire to include continuous variables in the zero-inflated standardization model, we used generalized additive models (GAM) to investigate the relationship of continuous covariates with CPUE. We investigated two sets of GAMs, one looking at the relationship of continuous covariates to the presence/absence of Gray Triggerfish and one looking at the relationship of continuous covariates to Gray Triggerfish catch.

For the presence/absence GAMs, each of the covariates had a non-linear effect on the presence of Gray Triggerfish (Figure 6 and Table 3). Probability of presence of Gray Triggerfish peaked at depths of 30-40 m, declining at shallower and deeper depths. The small peak at deep depths (~90 m) is an artifact of small sample sizes at these depths and likely not indicative of a real biological pattern. Probability of presence shows a distinct increasing trend as latitude increases. There does seem to be some high frequency cyclic structure to this effect, perhaps arising as an artifact of our spatial variation in sampling and the distribution of hard bottom habitat in the region. The probability of presences as a function of bottom temperature is parabolic in shape, peaking at approximately 26°C. Finally, the probability of gray triggerfish presence increases with DOY, through at least ~275 days, before sharply declining.

For the catch GAMs, each of the covariates had a non-linear effect on the catch of Gray Triggerfish (Figure 7 and Table 3). Highest catches of Gray Triggerfish occurred between 30-50 m of depth, declining at shallower and deeper depths. Catch of Gray Triggerfish increases as latitude increases through approximately 32°N. Above 32°N, catch initially decreases sharply before rebounding to reach peak levels at the northern extent of our sampling universe. Some of this high frequency cyclic structure is likely an artifact of the distribution of hard bottom habitat in the region and the distribution of our chevron trap universe. Catch of gray triggerfish seems to increase as bottom temperature increases through approximately 27°C before sharply declining. Once again the overall impression is that gray triggerfish catch as a function of bottom temperature is parabolic in shape. Finally, as is the case for the presence/absence GAMs, Gray Triggerfish catch seems to increase with DOY through approximately day 260 before sharply declining.

Based on these GAM analyses, in addition to year, we included the continuous covariates depth, latitude and DOY as polynomials in the full ZI model to allow for non-linear effects of these covariates on Gray Triggerfish CPUE. To determine the order of the polynomials, we rounded the GAM effective degrees of freedom (Table 3) to the nearest whole number, letting this number represent the highest polynomial order. Prior to model development, these continuous variables were centered and scaled to improve statistical convergence.

Selection of the covariates included in the final model (both zero-inflation and count sub-models) was done based on Bayesian information criterion (BIC; Schwarz 1978). We allowed the possibility that different covariates may appear in each of the sub-models. All analyses were performed in R (Version 3.1.0; R Development Core Team 2014). The zero-inflated models in R were developed using the function zeroinfl available in the package *pscl* (Jackman 2011; Zeileis et al. 2008).

Length and Age Composition

Gray Triggerfish lengths were measured following retrieval of each chevron trap set to the nearest centimeter prior to 2010 and to the nearest millimeter from 2010 to 2013. Measured lengths were either fork length or pinched total length in a given year. All total lengths were converted to fork length based on conversions developed from over 8,000 fish (Ballenger et al. 2012). Length percent compositions were calculated for each year using 1-cm length bins centered on the integer. All lengths are presented in mm. The first dorsal spine was used as the aging structure for Gray Triggerfish. Prior to 2008, Gray Triggerfish sampled for aging were a non-random sub-sample of the total number caught in each trap based on length bins. Since 2008, Gray Triggerfish for aging were either randomly subsampled from the total catch in each trap or all Gray Triggerfish were kept for aging. To correct for this difference in sampling methodology, age compositions prior to 2008 were scaled to the length composition in each year. For more details on these methods, see Ballenger et al. (2011). From 2008 to 2013, age composition calculations were straight forward as either a random sample or complete census of the catch was taken for age determination. Ages presented here are increment counts, regardless of collection date or edge type.

Results

Sampling Summary

A data set for analysis was obtained from a query of the SERFS database on June 20, 2014. Given the constraints mentioned above and removing any collections we are missing covariate data, from 1990 to 2013 we made 10,130 chevron trap monitoring deployments (Table 1), averaging 422 collections per year (range: 216-1329), following standard monitoring station sampling protocol. The average depth for these collections was 38 m, with annual averages ranging from 33 to 42 m. The average latitude was 31.95°N, with annual averages ranging from 30.88°N to 32.77°N. The average bottom temperature was 22.26^{o}C, with annual averages ranging from 18.9^{o}C to 25.0^{o}C. Finally, the average DOY was 193, with annual averages ranging from 149 to 217 days.

Nominal CPUE

Nominal catch per trap averaged 0.954 for the entire time series, with annual averages ranging from a low of 0.225 in 1990 to a high of 1.967 in 1995 (Table 4 and Figure 8).

Zero-Inflated CPUE

Preliminary model analyses clearly suggested that a zero-inflated negative binomial model (ZINB) was superior to a Poisson GLM, a negative binomial GLM, or zero-inflated Poisson model (ZIP). Both the best-fit Poisson GLM and best-fit negative binomial GLM, with overdispersions of 5.125 and 1.333, respectively, suggested overdispersion remained given these model structures (Table 5). Continued overdispersion despite these model structures suggests the catch data is zero-inflated and likely should be modeled using a zero-inflated model structure. While the overdispersion for the best-fit negative binomial GLM was mild, this model had a hard time converging and was unstable statistically. Comparing the ZIP and ZINB full models, BIC clearly suggested that a negative binomial error structure for the count model was superior to a Poisson error structure (Table 5), likely due to its ability to better account for the dispersion parameter by estimating theta directly in the model.

Step-wise selection using BIC starting with the full model removed a number of covariate polynomials from both the zero-inflation and count sub-models (Table 5). The only constraint on this selection was that the variable “Year” must be retained in the count sub-model of ZINB model. The resulting final model had the following form:

Zero-Inflation Sub-Model

$$\text{Abund}^* = offset(\ln(\text{soak time})) + \text{Depth} + \text{Depth}^2 + \text{Depth}^3 + \text{Latitude}^5 + \text{Temperature} + \text{DOY} + \text{DOY}^2 + \text{DOY}^3 + \text{DOY}^4 + \text{DOY}^5 + \text{DOY}^7 + \text{DOY}^9$$

Count Sub-Model

$$\text{Abund} = offset(\ln(\text{soak time})) + \text{Year} + \text{Depth} + \text{Depth}^2 + \text{Depth}^4 + \text{Latitude}^2 + \text{Latitude}^3 + \text{Latitude}^4 + \text{Latitude}^5 + \text{Latitude}^6 + \text{Latitude}^7 + \text{Temperature} + \text{Temperature}^2 + \text{DOY}^3 + \text{DOY}^5$$

where Abund* represents the catch data transformed to presence/absence data and Abund represents the observed catch data.

Standardized annual CPUE estimates normalized to the series average indicates that CPUE initially increased through the late 1990s before subsequently decreasing through the mid- to late-2000s (Figure 9). Since approximately 2006, CPUE in the region has been increasing generally (Figure 9).

Plots of annual coefficient of variation (CV) estimates indicate that 10,000 bootstraps were sufficient for CV estimates to stabilize (Figure 10). Standardization using the ZINB resulted in annual CV estimates of approximately 13.5%. Individual year CV estimates ranged from a low of 7.8% to a high of 25.4% in 2013 and 2003, respectively (Table 4).

A plot of the observed and predicted number of Gray Triggerfish caught suggests that the ZINB was moderately successful at capturing the observed catch pattern (Figure 11). While the ZINB predicts much fewer traps with 0 gray triggerfish catch, it predicts that we should have observed more traps with catches of 1 or 2 gray triggerfish than observed. Beyond that, the ZINB predicts at most only 7 Gray Triggerfish would be caught in any given trap, though we observed as many as 55 Gray Triggerfish in an individual trap.

Residual diagnostics suggest that there were at most only two outlier observations in the dataset represented by larger Pearson residuals (in excess of 15; Figure 12), though overall there is no strong indication of a pattern in the residuals or heteroscedascity when the residuals are plotted against included covariates (Figure 13 and 14). When Pearson residuals are compared to several potential covariates excluded from the final model (Chlorophyll-A concentration, dissolved oxygen concentration, Event (all traps included in a given trap set), longitude, month, salinity, and season) there is no strong indication of a pattern to the residuals or heteroscedascity, which indicates that no excluded covariates are critical to the model (Figures 15 and 16). Finally, looking at the spatial distribution of positive and negative Pearson residuals suggests no obvious spatial patterning of the residuals (Figure 17). This lack of spatial structure to the residuals also is supported by the sample variogram, which doesn't show any strong indication of spatial correlation in trap catches closer than 10 km to each other (Figure 18).

The final ZINB model suggests highly non-linear relationships among Gray Triggerfish catch and included covariates (depth, latitude, and day of year; Figure 19). For depth, as originally suggested, Gray Triggerfish catch peaks at depths between 30 and 50 m. For latitude, we see a highly nonlinear pattern though generally catches increase as one moves north. The high frequency cyclic structure could be an artifact of the underlying sampling distribution of the SERFS survey. For bottom temperature, catch of Gray Triggerfish generally increases as bottom temperature increases, reaching a peak at around 26-27^{o}C. Though sampling is limited at higher bottom temperatures, there is an indication that catches decrease at higher temperatures. Finally, DOY tends to have a highly non-linear effect on Gray Triggerfish catch. This highly nonlinear relationship is hard to explain at first glance.

Addendum 1

A Zero-Inflated Model of CPUE of Gray Triggerfish in US South Atlantic Waters Based on Fishery-Independent Chevron Trap Surveys

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Objective

This report presents a summary of the fishery-independent monitoring of gray triggerfish in the US South Atlantic region and includes data from the three monitoring programs (MARMAP, SEAMAP-SA, and SEFIS, known collectively as the Southeast Reef Fish Survey (SERFS)). Specifically, it presents annual catch per unit effort (CPUE) of gray triggerfish from chevron traps. Included here are annual CPUE estimates for chevron trap catches standardized by a zero-inflated statistical model for the years 1990-2013. The zero-inflated model accounts for the effects of potential covariates, other than year of capture, on annual CPUE estimates. Data presented in this report are based on the combined SERFS database accessed on June 20, 2014, and include data collected through the 2013 sampling season. The original report above presents a nominal index and a zero-inflated standardized index based on the same chevron trap catches. The difference between the two zero-inflated indices presented (original in above report and current model reported here) is how the covariates are treated in the model with the former treating the covariates as continuous variables that are modeled using polynomials in the model and the latter treating the covariates as categorical variables.

Methods

Survey Design and Gear

See the original report above for a description of the sample collection methods

Oceanographic Data

See the original report above for details regarding the collection of oceanographic data via a CTD.

Data and Treatment

Data and Nominal CPUE Estimation

See the original report above for details regarding the data available and nominal CPUE estimation.

Zero-Inflated Model CPUE Standardization

CPUE was standardized among years using a zero-inflated count model. Such a treatment of the data was suggested at the SEDAR 32 data workshop due to the poor fit of the lognormal error distribution for the positive component of the delta-GLM model to the observed data (see Ballenger et al. 2013, Figure 9). Investigation of this technique to model CPUE data also was suggested during the Fishery-Independent Survey Independent Review for the South Atlantic (SEFSC 2012). As is the case with many ecological count data sets (Zuur et al. 2009), the observed CPUE data appeared to be zero-inflated based on preliminary analyses (Figure 3), suggesting the appropriateness of zero-inflated count data models.

Briefly, we provide some background information regarding zero-inflated count data models. For a more complete discussion, see Chapter 11 in Zuur et al. (2009). Zeileis et al. (2008) provides a nice overview and comparison of Poisson, negative binomial, and zero-inflated models in R. Some textbooks devoting sections to the discussion of zero-inflated models include Cameron and Trivedi (1998), Hardin and Hilbe (2007), or Hilbe (2007).

The concept of zero inflation derives from the observation that in many ecological, economic, and social studies there are far more zeros in count data than what would be expected for a Poisson or negative binomial distribution. As such, zero inflation means that we have far more zeros than we would expect. Ignoring zero inflation when it exists can have two major consequences, namely the estimated parameters and standard errors may be biased and the excessive number of zeros can cause overdispersion (Zuur et al. 2009).

Zeros due to design and observer errors are called false zeros or false negatives while structural and "animal" zeros are known as positive zeros, true zeros, or true negatives (Zuur et al. 2009). To address these different sources of zeros, two distinctive classes of zero-inflated models have been developed, two-part (hurdle) and mixture models, with the difference between the two classes arising due to differences in how they deal with zeros. Two-part models do not discriminate between the four different types of zeros and simply treat a zero as a zero whereas mixture models account for the type of zero.

Mixture models (zero-inflated Poisson (ZIP) and zero-inflated negative binomial (ZINB)) treat zeros via two different processes: the binomial process and the count process (Zuur et al. 2009). A binomial generalized linear model is used to model the probability of measuring a zero while the count process is modeled by a Poisson or negative binomial GLM. As such, the fundamental difference between hurdle and mixture models is that the count process can produce zeros in mixture models but not in hurdle models (Zuur et al. 2009). In such a setup, the zeros resulting from the count process model represent true zeros, while the binomial GLM models the probability of measuring a false zero versus all other types of data (counts and true zeros; Zuur et al. 2009). In short, the probability functions of a ZINB are:

$$f(y_i = 0) = \pi_i + (1 - \pi_i) * \left(\frac{k}{\mu_i + k}\right)^k$$

$$f(Y_i = y_i | y_i > 0) = (1 - \pi_i) * \frac{\Gamma(y_i + k)}{\Gamma(k) * \Gamma(y_i + 1)} * \left(\frac{k}{\mu_i + k}\right)^k * \left(1 - \frac{k}{\mu_i + k}\right)^k$$

for the binomial component and the non-zero component, respectively. In ZINB, the expected mean and variance are slightly different due to the definition of the probability functions. The mean and variance of a ZINB are:

$$\mathrm{E}(Y_i) = \mu_i * (1 - \pi_i)$$

$$\mathrm{var}(Y_i) = (1-\pi_i) * \left(\mu_i + \frac{\mu_i^2}{k}\right) + \mu_i^2 * \left(\pi_i^2 + \pi_i\right).$$

If the probability of false zeros is 0, the mean and variance of the negative binomial GLM are equal.

In the development of the ZINB CPUE model for Gray Triggerfish, we modeled CPUE as catch per trap, compared to the traditional method of calculating catch per trap per hour. We included soak time as an offset term instead of creating a catch rate by dividing the catch per trap by the soak time or sample duration. By defining this offset variable we adjust for the amount of opportunity for the gear to capture a fish (e.g. a deployment with a soak time of 120 minutes has twice the opportunity than a deployment with a soak time of 60 minutes).

Similar to dGLM, ZINB models can account for effects of different covariates on observed counts. The same or different covariates can be included in the binomial sub-model and catch sub-model. In initial investigations we considered the following covariates in addition to year:

- Depth
- Bottom temperature
- Longitude
- Latitude
- Day of Year (DOY)

Other covariates in the data set that could have been considered included bottom salinity, month, season, dissolved oxygen concentration, chlorophyll-A concentration, nitrite (NO_2) concentration, nitrate (NO_3) concentration, and phosphate (PO_4) concentration. We didn't consider bottom salinity as a potential covariate due to its general lack of variability in oceanic waters and preliminary investigations suggesting there was little relationship between Gray Triggerfish CPUE and bottom salinity. We didn't consider month or season as a covariate as each is correlated to a high degree with our included covariate DOY. Given DOY gives more temporal resolution, the assumption was made that it would provide greater power in standardizing Gray Triggerfish CPUE with regards to within year day of sampling differences. Finally, we didn't consider the last five potential covariates due to missing values on a large number of trap sets data for these variables, primarily due to the lack of equipment to collect these variables historically.

Prior to inclusion of the considered covariates in the full model, we used preliminary analyses to investigate the possibility of collinearity between any of the variables. A pairs plot of continuous covariates revealed high correlation between latitude and longitude (due to the shape of the survey region), and moderate correlation between bottom temperature and depth and bottom temperature and DOY (Figure 4). Variance inflation factor (VIF) estimates for all considered covariates were all <2 (Table 2).

Box plots of the covariates (depth, latitude, bottom temperature, and DOY) among years showed no obvious strong collinearity (Figure 5). With regards to sampling depth, sampling throughout the entire period appeared fairly homogenous, with the possible exception of 1992. With regards to latitude there is some evidence that from 1990-1992 we sampled more northern waters, followed by fairly homogenous sampling from 1993-2009. Most notable is the expansion in 2010, which corresponds to the first sampling season including SEFIS. Since 2010 the median latitude of sampling has shifted south with an overall broader range of sampling. 1999 was slightly anomalous in that the latitude distribution is restricted compared to surrounding years, with it being more similar to the early years of the survey. For bottom temperature, there is evidence that 2003 (and to a lesser degree 2004) was an exceptionally cold year for bottom temperatures at our sampling locations and times. Conversely, bottom temperatures were warmer than average in 1991 and 1995. Finally, for DOY there does seem to be more year to year variability in days sampled. This is to be expected given the nature of the survey and weather constraints. Most notably, sampling appeared to occur earlier than average in 1990 and 1992 and later than average in 1991 and 2010. Also, sampling in 1999 was restricted temporally compared to other years.

Due to the desire to inform the binning structure of covariates in the zero-inflated standardization model, we used generalized additive models (GAM) to investigate the relationship of each covariate with CPUE. We investigated two sets of GAMs, one looking at the relationship of continuous covariates to the presence/absence of Gray Triggerfish and one looking at the relationship of continuous covariates to Gray Triggerfish catch.

For the presence/absence GAMs, each of the covariates had a non-linear effect on the presence of Gray Triggerfish (Figure 6 and Table 3). Probability of presence of Gray Triggerfish peaked at depths of 30-40 m, declining at shallower and deeper depths. The small peak at deep depths (~90 m) is an artifact of small sample sizes at these depths and likely not indicative of a real biological pattern. Probability of presence shows a distinct increasing trend as latitude increases. There does seem to be some high frequency cyclic structure to this effect, perhaps arising as an artifact of our spatial variation in sampling and the distribution of hard bottom habitat in the region. The probability of presences as a function of bottom temperature is parabolic in shape, peaking at approximately 26^{o}C. Finally, the probability of gray triggerfish presence increases with DOY, through at least ~275 days, before sharply declining.

For the catch GAMs, each of the covariates had a non-linear effect on the catch of Gray Triggerfish (Figure 7 and Table 3). Highest catches of Gray Triggerfish occurred between 30-50 m of depth, declining at shallower and deeper depths. Catch of Gray Triggerfish increases as latitude increases through approximately 32^{o}N. Above 32^{o}N, catch initially decreases sharply before rebounding to reach peak levels at the northern extent of our sampling universe. Some of this high frequency cyclic structure is likely an artifact of the distribution of hard bottom habitat in the region and the distribution of our chevron trap universe. Catch of gray triggerfish seems to increase as bottom temperature increases through approximately 27^{o}C before sharply declining. Once again the overall impression is that gray triggerfish catch as a function of bottom temperature is parabolic in shape. Finally, as is the case for the presence/absence GAMs, Gray Triggerfish catch seems to increase with DOY through approximately day 260 before sharply declining.

Based on these GAM analyses, in addition to year, we decided to include the categorical covariates depth and latitude and the continuous covariates bottom temperature and DOY in the full ZI model (Table 8). To inform the bin structure, we used the GAM analyses relating catch of Gray Triggerfish to each covariate (Figures 6 and 7) to identify periods of relatively homogenous catch of Gray Triggerfish with respect to the covariate. This resulted in 3 and 4 bins for the covariates depth and latitude, respectively (Table 8). Members of the SEDAR 41 Index Working Group provided guidance on the number of bins and potential bin break points during the SEDAR 41 data workshop. SEDAR 41 Index Working group panel members also suggested that bottom temperature and day of year should be included as linear predictors in the ZINB model as the effect of each of these covariates was largely linear in nature.

Selection of the covariates included in the final model (both zero-inflation and count sub-models) was done based on Akaike's information criterion (AIC; Akaike 1973). We allowed the possibility that different covariates may appear in each of the sub-models. All analyses were performed in R (Version 3.1.0; R Development Core Team 2014). The zero-inflated models in R were developed using the function zeroinfl available in the package *pscl* (Jackman 2011; Zeileis et al. 2008).

Results

Sampling Summary

See the original report above for the sampling summary.

Zero-Inflated CPUE

Step-wise forward selection using AIC add all covariates (depth, latitude, bottom temperature, and DOY) to both the zero-inflation and count sub-models (Table 9). In addition, the covariate year was added to the zero-inflation sub-model. The only constraint on this selection was that the variable "Year" must be retained in the count sub-model of ZINB model. The resulting final model had the following form:

Zero-Inflation and Count Sub-Model

$$\text{Abund} = offset(\ln(\text{soak time})) + \text{Year} + \text{Depth} + \text{Latitude} + \text{Temperature} + \text{DOY}$$

where Abund represents the catch data transformed to presence/absence data in the zero-inflation model and the observed catch data in the count model.

Standardized annual CPUE estimates normalized to the series average indicates that CPUE initially increased through the late 1990s before subsequently decreasing through the mid- to late-2000s (Figure 9). Since approximately 2006, CPUE in the region has been increasing generally (Figure 9).

In the bootstrap to estimate variability in the annual relative abundance index we observed a convergence rate of 96.8%, resulting in 1,936 individual bootstraps being used in variability estimation. For each of these bootstraps we calculated an observed relative index based on the bootstrap sampling (Figure 21), with those giving the same overall pattern of relative abundance observed in the base model. Plots of annual variance and coefficient of variation (CV) estimates indicate that 1,936 bootstraps were sufficient for these measures to stabilize (Figure 22). Standardization using the ZINB resulted in annual CV estimates of approximately 16%. Individual year CV estimates ranged from a low of 9% to a high of 28% in 2013 and 2003, respectively (Table 10).

A plot of the observed and predicted number of Gray Triggerfish caught suggests that the ZINB was moderately successful at capturing the observed catch pattern (Figure 23). While the ZINB predicts much fewer traps with 0 gray triggerfish catch, it predicts that we should have observed more traps with catches of 1 or 2 gray triggerfish than observed. Beyond that, the ZINB predicts at most only 6 Gray Triggerfish would be caught in any given trap, though we observed as many as 55 Gray Triggerfish in an individual trap.

Residual diagnostics suggest that there were at most only two outlier observations in the dataset represented by larger Pearson residuals (in excess of 15; Figure 24), though overall there is no strong indication of a pattern in the residuals or heteroscedascity when the residuals are plotted against included covariates (Figure 25 and 26). When Pearson residuals are compared to several potential covariates excluded from the final model (Chlorophyll-A concentration, dissolved oxygen concentration, Event (all traps included in a given trap set), longitude, month, salinity, and season) there is no strong indication of a pattern to the residuals or heteroscedascity, which indicates that no excluded covariates are critical to the model (Figures 27 and 28). Finally, looking at the spatial distribution of positive and negative Pearson residuals suggests no obvious spatial patterning of the residuals (Figure 29). This lack of spatial structure to the residuals also is supported by the sample variogram, which doesn't show any strong indication of spatial correlation in trap catches closer than 10 km to each other (Figure 30).

The final ZINB model suggests non-linear relationships among Gray Triggerfish catch and the covariates depth, latitude, and bottom temperature and a generally linear effect of DOY (Figure 31). For depth, as originally suggested, Gray Triggerfish catch peaks in bin 2, which corresponds to depths between 30 and 59 m.   For latitude, we see a generally bimodal distribution with catch peaking in bins 2 (31-32.49^{o}N) and 4 (>=34^{o}N). For bottom temperature, catch of Gray Triggerfish exhibits a sigmoidal shape, with catch peaking at the highest temperatures observed. Finally, DOY tends to be positively correlated with Gray Triggerfish catch, with catch increasing nearly linearly throughout the season.

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Tables

Table 1: Number of chevron trap deployments on live/hard-bottom areas and information associated with chevron trap deployments included in nominal and standardized catch per unit effort (CPUE) calculations for Gray Triggerfish.

		Depth (m)				Latitude (°N)				Temperature (°C)				Day of Year			
			Range				Range				Range				Range		
Year	**n**	**Avg**	**Min**	**Max**	**SE**	**Avg**	**Min**	**Max**	**SE**	**Avg**	**Min**	**Max**	**SE**	**Avg**	**Min**	**Max**	**SE**
1990	307	34	17	93	0.71	32.52	30.42	33.82	0.0370	21.9	18.2	27.8	0.144	149	114	222	1.65
1991	267	33	17	93	0.70	32.65	30.75	34.61	0.0517	25.0	15.9	27.7	0.107	217	163	268	2.04
1992	288	34	17	62	0.59	32.77	30.42	34.32	0.0407	21.3	15.3	24.5	0.161	155	92	227	2.51
1993	410	35	16	94	0.67	32.39	30.43	34.32	0.0383	22.8	17.7	28.5	0.133	177	131	226	1.45
1994	398	39	16	93	0.71	32.35	30.74	33.82	0.0304	22.8	18.1	26.9	0.103	176	130	300	1.82
1995	334	35	16	60	0.72	32.19	29.94	33.75	0.0442	24.5	20.1	28.3	0.131	192	124	299	2.53
1996	376	38	14	94	0.76	32.23	27.92	34.33	0.0598	21.8	14.2	27.0	0.166	189	121	261	2.24
1997	394	39	15	93	0.79	32.01	27.87	34.59	0.0790	22.7	16.8	28.0	0.117	193	126	273	1.49
1998	445	42	14	92	0.79	32.06	27.44	34.59	0.0728	20.7	9.5	28.6	0.229	182	126	231	1.83
1999	216	38	15	75	0.88	31.90	27.27	34.41	0.1188	22.8	17.9	28.8	0.140	202	154	272	1.81
2000	292	38	15	92	0.83	32.38	28.95	34.28	0.0654	23.9	18.0	28.5	0.136	195	138	292	2.36
2001	245	39	14	91	0.96	32.35	27.87	34.28	0.0711	23.4	16.0	29.2	0.172	205	144	298	2.22
2002	244	38	13	94	0.94	31.87	27.86	33.95	0.0853	24.2	15.2	28.3	0.210	207	169	268	1.90
2003	225	40	16	92	0.95	32.07	27.43	34.33	0.1083	18.9	13.4	25.1	0.142	203	155	266	2.12
2004	290	41	14	91	0.98	32.26	29.00	33.97	0.0615	20.9	16.7	25.8	0.161	176	127	303	2.18
2005	303	38	15	69	0.74	32.08	27.33	34.32	0.0842	23.0	18.0	28.5	0.170	191	124	273	2.84
2006	293	38	15	94	0.88	32.29	27.27	34.39	0.0870	22.5	15.0	26.7	0.179	203	158	272	1.95
2007	336	38	15	92	0.83	32.18	27.33	34.33	0.0781	23.2	15.3	28.9	0.161	201	142	268	2.05
2008	303	38	15	92	0.81	32.17	27.27	34.59	0.0841	21.9	15.2	27.2	0.145	195	127	275	2.60
2009	396	36	14	91	0.75	32.25	27.27	34.60	0.0822	22.5	15.4	27.2	0.133	202	127	282	2.39
2010	618	39	14	92	0.58	31.61	27.34	34.59	0.0667	21.1	12.3	29.4	0.154	210	125	301	2.06
2011	688	41	15	93	0.58	30.88	27.23	34.54	0.0699	21.6	14.8	28.8	0.148	208	140	299	1.72
2012	1133	40	15	94	0.48	31.86	27.23	35.02	0.0642	22.1	12.9	27.8	0.102	194	116	285	1.32
2013	1329	38	15	92	0.39	31.26	27.23	35.01	0.0545	22.1	12.4	28.1	0.084	197	115	278	1.28

Table 2. Variance inflation factor (VIF) estimates and degrees of freedom (df) for all considered covariates.

Variable	VIF	df
Year	1.456	23
Depth	1.328	1
Bottom Temperature	1.936	1
Latitude	1.199	1
Day of Year	1.455	1

Table 3. Generalized Additive Model (GAM) results and full model polynomial order for the zero inflation sub-model (ZI) and count sub-model (Count) for the zero-inflated index model. EDF = effective degrees of freedom of smoothed spline.

	Presence/Absence GAM		Catch GAM		Polynomials	
Variable	EDF	p-value	EDF	p-value	Zero Inflation	Count
Depth	8.82	<0.0001	8.95	<0.0001	9	9
Latitude	8.92	<0.0001	8.97	<0.0001	9	9
Temperature	5.57	<0.0001	7.17	<0.0001	6	7
Day of Year	8.60	<0.0001	8.80	<0.0001	9	9

Table 4. Gray Triggerfish nominal catch per unit effort (CPUE) and zero-inflated negative binomial (ZINB) standardized CPUE for chevron traps. N = number of included traps, positive = proportion of included collections positive for Gray Triggerfish, CV = coefficient of variation, and normalized = annual index value normalized to its long-term mean to give relative abundance over time.

				Nominal			ZINB Standardized		
Year	n	Positive	% Positive	CPUE	CV	Normalized	CPUE	CV	Normalized
1990	307	34	11.07%	0.225	0.226	0.235	0.123	0.201	0.264
1991	267	121	45.32%	1.371	0.100	1.432	0.510	0.116	1.094
1992	288	83	28.82%	0.663	0.147	0.693	0.464	0.140	0.996
1993	410	118	28.78%	0.727	0.114	0.759	0.387	0.108	0.832
1994	398	153	38.44%	1.121	0.104	1.171	0.475	0.109	1.020
1995	334	150	44.91%	1.967	0.128	2.055	0.648	0.098	1.390
1996	376	144	38.30%	1.939	0.148	2.026	0.773	0.104	1.659
1997	394	161	40.86%	1.779	0.124	1.859	0.693	0.103	1.487
1998	445	113	25.39%	1.108	0.143	1.158	0.799	0.127	1.715
1999	216	55	25.46%	0.833	0.189	0.871	0.361	0.164	0.774
2000	292	82	28.08%	0.726	0.189	0.759	0.277	0.171	0.595
2001	245	82	33.47%	0.918	0.122	0.960	0.435	0.126	0.934
2002	244	98	40.16%	1.311	0.123	1.370	0.699	0.142	1.500
2003	225	29	12.89%	0.236	0.204	0.246	0.423	0.254	0.908
2004	290	74	25.52%	0.634	0.151	0.663	0.670	0.134	1.437
2005	303	92	30.36%	1.083	0.152	1.131	0.339	0.127	0.727
2006	293	66	22.53%	0.512	0.162	0.535	0.272	0.146	0.584
2007	336	105	31.25%	0.932	0.172	0.973	0.420	0.147	0.902
2008	303	65	21.45%	1.066	0.193	1.114	0.402	0.154	0.863
2009	396	80	20.20%	0.649	0.175	0.678	0.323	0.149	0.694
2010	618	133	21.52%	0.524	0.127	0.548	0.303	0.137	0.651
2011	688	141	20.49%	0.757	0.130	0.791	0.359	0.112	0.770
2012	1133	323	28.51%	0.954	0.088	0.997	0.493	0.087	1.059
2013	1329	357	26.86%	0.933	0.077	0.975	0.534	0.078	1.147

Table 5. Results of Bayesian information criterion (BIC) selection, including some best-fit preliminary models (GTPoissonSel, GTNBSel, GTZIPAll, GTZINBVisual) based on different model structures from the initial full model mentioned in the report.

Step	Model	Variable	Sub-Model	BIC	Difference
	GTPoissonSel			33183.9	-11321.40
	GTZIPAll			26484.0	-4621.55
	GTZINBAll			22232.1	-369.59
1	ZINB1ZISub2	-Year	Zero Inflation	22070.9	-208.41
2	ZINB2CAdd9	+Latitude^7	Count	22031.0	-168.54
3	ZINB3ZISub17	-Latitude^3	Zero Inflation	22021.8	-159.35
4	ZINB4CSub6	DOY	Count	22012.7	-150.19
5	ZINB5ZISub19	-Latitude^6	Zero Inflation	22003.9	-141.43
6	ZINB6CSub11	-DOY^7	Count	21995.0	-132.56
7	ZINB7CSub21	-Temperature^4	Count	21986.4	-123.91
8	ZINB8CSub10	-DOY^6	Count	21977.6	-115.13
9	ZINB9ZISub13	-DOY^8	Zero Inflation	21969.3	-106.87
10	ZINB10ZISub11	-DOY^6	Zero Inflation	21961.3	-98.85
	GTNBSel			21956.3	-93.78
11	ZINB11CSub21	-Temperature^6	Count	21953.5	-91.01
12	ZINB12CSub6	-DOY^2	Count	21945.9	-83.40
13	ZINB13ZISub13	-Latitude	Zero Inflation	21938.5	-76.07
14	ZINb14ZISub14	-Latitude^4	Zero Inflation	21929.6	-67.16
15	ZINB15CSub9	-Latitude	Count	21922.2	-59.74
16	ZINB16CSub18	-Temperature^5	Count	21915.7	-53.22
17	ZINb17CSub7	-DOY^4	Count	21909.4	-46.89
18	ZINB18CSub16	-Temperature^3	Count	21903.2	-40.77
19	ZINB19ZISub17	-Temperature^3	Zero Inflation	21897.0	-34.48
20	ZINB20ZISub17	-Temperature^4	Zero Inflation	21890.1	-27.58
21	ZINB21ZISub16	-Temperature^2	Zero Inflation	21882.7	-20.18
22	ZINB22ZISub13	-Latitude^2	Zero Inflation	21878.4	-15.88
23	ZINB23ZISub5	-Depth^4	Zero Inflation	21874.3	-11.84
24	ZINB24CAdd1	+Depth^4	Count	21870.9	-8.44
25	ZINB25CSub5	-Depth^3	Count	21862.5	0.00

Table 6. Length composition of Gray Triggerfish collected by chevron trap during the Southeast Reef Fish Survey from 1990 to 2013. Lengths are fork length in mm and composition is in percent of fish falling into each 1-cm bin of the total for each year.

Length (mm)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
100	0.0	0.3	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
110	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
120	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
130	0.0	0.3	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
140	2.6	0.3	0.0	1.0	0.2	0.6	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
150	1.3	2.5	1.0	1.7	0.0	0.5	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.2	0.2	0.0	0.0
160	1.3	6.0	1.5	0.3	0.5	1.6	0.6	0.2	0.6	1.1	0.0	0.8	0.3	0.0	1.5	0.0	0.6	0.0	0.9	0.0	0.0	0.3	0.0	0.0
170	1.3	8.0	0.0	2.4	0.5	1.6	0.9	0.2	0.8	0.0	0.4	0.4	2.0	1.5	0.8	0.3	0.0	0.2	0.3	0.0	0.0	0.0	0.1	0.0
180	0.0	10.1	2.0	2.7	1.8	1.9	1.2	0.4	0.4	0.5	0.4	0.8	1.7	0.0	1.2	0.5	2.3	0.7	2.1	0.0	0.0	0.3	0.9	0.6
190	6.4	6.5	3.4	1.3	2.2	1.8	1.7	1.9	0.0	0.5	1.1	1.2	2.3	1.5	1.9	0.3	1.7	0.5	0.9	0.0	0.0	0.3	0.4	0.4
200	7.7	5.3	4.4	2.4	1.6	1.1	1.3	1.3	0.6	4.7	1.1	4.7	1.4	1.5	2.3	0.5	1.2	0.7	2.4	0.9	0.0	1.2	0.6	0.6
210	3.9	5.3	2.5	2.0	2.7	2.5	1.8	1.3	0.8	1.6	1.5	2.3	5.8	0.0	1.5	0.3	1.2	0.7	1.5	0.0	0.2	0.7	0.5	0.8
220	6.4	5.3	3.4	6.0	2.0	3.4	1.4	1.6	0.6	3.7	0.0	3.1	5.5	3.0	1.5	0.5	4.6	2.8	3.6	1.3	1.2	1.0	1.5	1.7
230	5.1	3.5	2.5	6.0	2.7	4.8	0.9	2.0	1.0	4.2	1.5	1.9	4.0	0.0	1.9	0.8	2.3	0.7	0.9	0.6	0.3	1.0	1.8	1.0
240	1.3	4.8	4.9	8.7	3.4	3.0	2.9	1.7	1.9	2.1	0.4	3.5	4.3	3.0	3.1	2.1	4.0	1.7	0.6	1.3	1.7	1.7	1.7	1.4
250	5.1	3.0	3.9	6.0	2.7	3.0	2.5	2.3	3.1	2.1	2.6	2.7	4.3	1.5	5.3	1.6	2.3	3.1	1.2	2.2	1.7	1.3	3.0	2.4
260	0.0	3.0	2.9	6.0	3.1	2.2	5.3	1.3	3.1	4.7	1.5	3.9	3.2	1.5	4.6	2.4	5.8	4.5	3.0	7.8	2.1	3.4	8.0	4.5
270	1.3	3.8	5.4	6.0	3.1	1.1	4.8	2.3	2.7	4.2	2.2	2.7	2.6	1.5	4.6	2.4	2.3	3.8	1.5	1.9	2.7	2.9	4.1	2.4
280	2.6	3.3	2.9	7.1	4.7	2.1	8.4	3.2	4.2	2.6	2.6	3.5	2.6	1.5	7.3	1.3	2.3	2.8	2.1	4.4	4.4	3.2	4.6	2.6
290	1.3	3.5	5.9	5.0	5.2	3.0	8.2	3.9	4.8	6.8	3.4	3.1	2.6	4.5	8.4	2.6	3.5	4.5	1.8	3.1	5.6	3.9	3.6	3.9
300	5.1	3.5	2.5	4.7	5.2	2.2	9.3	6.3	4.4	5.3	5.6	2.3	4.6	7.5	7.3	3.1	6.9	7.8	3.9	16.0	4.8	4.2	7.8	7.1
310	3.9	2.5	8.3	6.4	6.0	1.5	10.0	7.4	7.3	4.7	4.8	3.1	3.7	9.0	5.7	3.9	4.0	4.5	2.7	7.8	6.1	5.2	3.6	7.1
320	0.0	1.3	4.4	1.7	3.4	1.5	8.1	8.5	8.1	5.3	6.3	5.8	3.5	3.0	6.5	6.0	2.3	5.7	2.7	6.6	5.1	5.4	3.6	6.5
330	0.0	1.8	1.0	3.4	6.0	3.9	9.2	9.4	7.1	5.8	7.1	4.7	5.2	10.5	7.3	6.3	1.7	4.7	3.9	6.9	8.0	6.7	2.8	6.9
340	9.0	1.8	4.4	2.4	5.2	5.8	4.4	7.9	8.3	2.6	7.8	9.3	4.0	6.0	6.1	7.3	9.8	10.2	11.1	11.3	8.5	6.6	7.6	13.9
350	2.6	2.0	3.9	1.7	3.1	5.5	4.6	8.7	7.5	1.1	6.3	7.8	3.2	1.5	5.0	7.3	6.9	7.8	3.3	5.3	8.0	8.1	3.8	6.7
360	5.1	0.8	2.5	2.4	6.3	6.4	1.9	7.4	8.3	4.2	14.1	6.2	5.5	9.0	2.3	7.1	2.9	5.2	6.9	3.8	6.1	7.2	4.4	6.1
370	3.9	0.8	2.9	2.4	3.6	5.5	2.2	7.0	8.1	6.3	8.6	6.6	4.0	7.5	3.4	7.6	2.9	3.3	7.8	3.5	5.0	6.6	4.7	3.0
380	3.9	1.0	2.5	1.7	3.1	5.2	1.8	3.8	3.7	7.4	5.2	2.7	2.9	4.5	1.9	6.3	5.8	7.3	11.4	6.3	5.0	5.6	8.1	6.1
390	2.6	1.0	2.9	1.0	3.6	5.7	2.0	1.8	4.4	4.2	4.5	3.5	6.0	6.0	1.9	7.3	4.0	3.6	5.4	1.6	5.0	4.4	4.2	2.3
400	6.4	1.3	2.5	1.0	6.7	6.0	0.3	2.5	2.1	4.7	3.4	3.1	2.3	3.0	2.7	6.0	4.0	2.6	3.6	1.6	4.4	5.2	3.9	1.8
410	3.9	1.5	3.9	1.7	2.5	4.2	1.1	1.9	2.1	2.1	2.6	1.9	3.5	3.0	0.8	5.0	2.3	2.4	3.0	0.6	3.1	3.7	3.8	1.9
420	2.6	0.5	2.0	0.3	1.8	2.7	0.9	1.3	1.9	1.1	2.2	1.9	3.5	1.5	0.8	5.2	4.0	2.8	4.5	2.5	2.2	2.7	4.8	3.0

430	1.3	1.3	1.0	1.3	2.5	2.1	0.7	0.7	0.8	2.6	1.5	2.3	1.7	6.0	0.8	3.4	1.7	2.1	1.5	0.3	2.6	2.2	1.2	0.9
440	0.0	1.0	3.4	0.7	0.7	1.9	0.2	0.7	0.4	2.6	0.4	1.6	1.7	0.0	0.4	0.8	1.2	1.2	1.2	0.9	1.4	1.7	0.9	1.0
450	1.3	0.8	0.0	0.3	2.0	2.7	0.4	0.4	0.4	0.0	0.7	1.9	1.4	0.0	0.8	1.3	0.6	0.2	0.9	0.9	1.2	0.8	1.5	0.6
460	0.0	1.3	1.5	0.0	0.7	1.2	0.2	0.3	0.0	0.0	0.0	0.0	0.3	1.5	0.4	0.0	1.7	1.2	2.4	0.6	1.0	1.0	1.4	0.9
470	0.0	0.3	1.0	0.0	0.2	0.6	0.2	0.4	0.0	0.5	0.0	0.4	0.0	0.0	0.4	0.3	0.6	0.5	0.0	0.0	1.2	0.5	0.1	0.9
480	0.0	0.3	1.0	0.7	0.7	0.6	0.1	0.0	0.4	0.5	0.0	0.4	0.3	0.0	0.0	0.0	0.6	0.2	0.6	0.0	0.3	0.5	0.2	0.2
490	0.0	0.0	0.5	0.7	0.0	0.0	0.0	0.1	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.2	0.2	0.3	0.2
500	0.0	0.3	0.0	1.0	0.0	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.4	0.3
510	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.2
520	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.2	0.0	0.0	0.0
530	0.0	0.3	0.5	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.1	0.2
540	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
550	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
560	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
570	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
580	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
590	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
610	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Fish	78	398	204	298	447	669	1198	958	519	190	269	258	348	67	262	382	174	423	334	319	586	595	1148	1270
Traps	41	134	88	118	154	156	179	194	124	62	92	99	112	34	96	108	75	123	72	90	216	169	341	367

Table 7. Age composition of Gray Triggerfish collected by chevron trap during the Southeast Reef Fish Survey from 1990 to 2013. Ages are increment counts and composition is in percent of fish falling into each 1-year bin of the total for each year. *Number of fish 1990-2007 is an estimate based on the correction of ages by length composition as described in the text.

Age	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
0	0.5	0.0	0.6	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	53.5	11.0	8.4	9.7	4.5	5.5	5.6	2.1	12.4	5.6	20.1	16.3	1.4	9.9	0.8	3.2	3.1	13.2	17.2	13.7	10.1	3.6	7.8
2	27.5	35.4	28.9	22.4	25.2	18.8	15.6	6.6	18.3	15.3	20.5	24.7	14.9	22.2	6.4	14.5	17.3	15.8	35.7	35.0	17.5	16.0	26.0
3	6.4	22.0	34.1	26.7	28.9	28.5	28.1	26.8	25.7	26.1	26.0	20.5	32.4	36.8	23.2	28.5	27.3	26.1	29.8	31.5	27.8	22.7	32.2
4	6.9	21.1	13.6	22.4	22.9	26.1	25.4	32.3	20.3	30.6	21.6	16.3	21.6	17.0	33.8	20.4	28.4	18.8	10.1	11.2	19.8	24.7	16.2
5	2.1	6.2	8.1	10.8	12.5	13.5	15.1	18.7	14.9	13.8	8.1	9.7	18.9	8.0	19.8	22.0	13.1	12.9	4.6	6.6	13.9	20.0	10.7
6	1.5	3.3	5.2	5.6	1.9	3.6	5.7	8.5	5.4	4.5	0.7	5.3	8.1	2.4	8.4	5.9	6.0	4.8	2.1	0.0	5.6	4.2	3.3
7	1.0	1.0	0.6	1.9	2.3	2.5	2.7	3.8	2.5	2.2	2.2	5.5	2.7	3.3	5.6	3.2	2.8	4.4	0.0	0.5	2.4	4.0	1.9
8	0.0	0.0	0.3	0.6	1.0	0.8	1.3	1.1	0.0	1.5	0.7	1.1	0.0	0.5	0.8	0.0	1.4	2.9	0.0	0.5	1.5	2.9	1.4
9	0.5	0.0	0.0	0.0	0.7	0.4	0.4	0.2	0.5	0.4	0.0	0.3	0.0	0.0	0.6	1.1	0.6	0.4	0.4	0.5	1.5	1.1	0.3
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	1.1	0.0	0.4	0.0	0.5	0.0	0.2	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.4	0.0	0.0	0.0	0.2	0.2
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0
Fish*	389	209	308	465	686	1219	963	530	202	268	273	361	74	212	358	186	352	272	238	197	338	449	909
Traps	47	70	112	142	134	166	164	118	60	86	78	102	33	74	99	64	96	64	79	97	116	190	281

Addendum Tables

Table 8. Covariate binning structure for the ZINB model. For the categorical variables depth and latitude the binning structure was informed by GAM results relating the catch of Gray Triggerfish to each covariate. GAM model results suggested that the covariates bottom temperature and day of year should be included in the model as continuous covariates.

	Bins			
Variable	**1**	**2**	**3**	**4**
Depth	<30	30-59	>=60	
Latitude	<31	31-32.49	32.5-33.99	>=34
Bottom Temperature	Continuous covariate as linear predictor			
Day of Year	Continuous covariate as linear predictor			

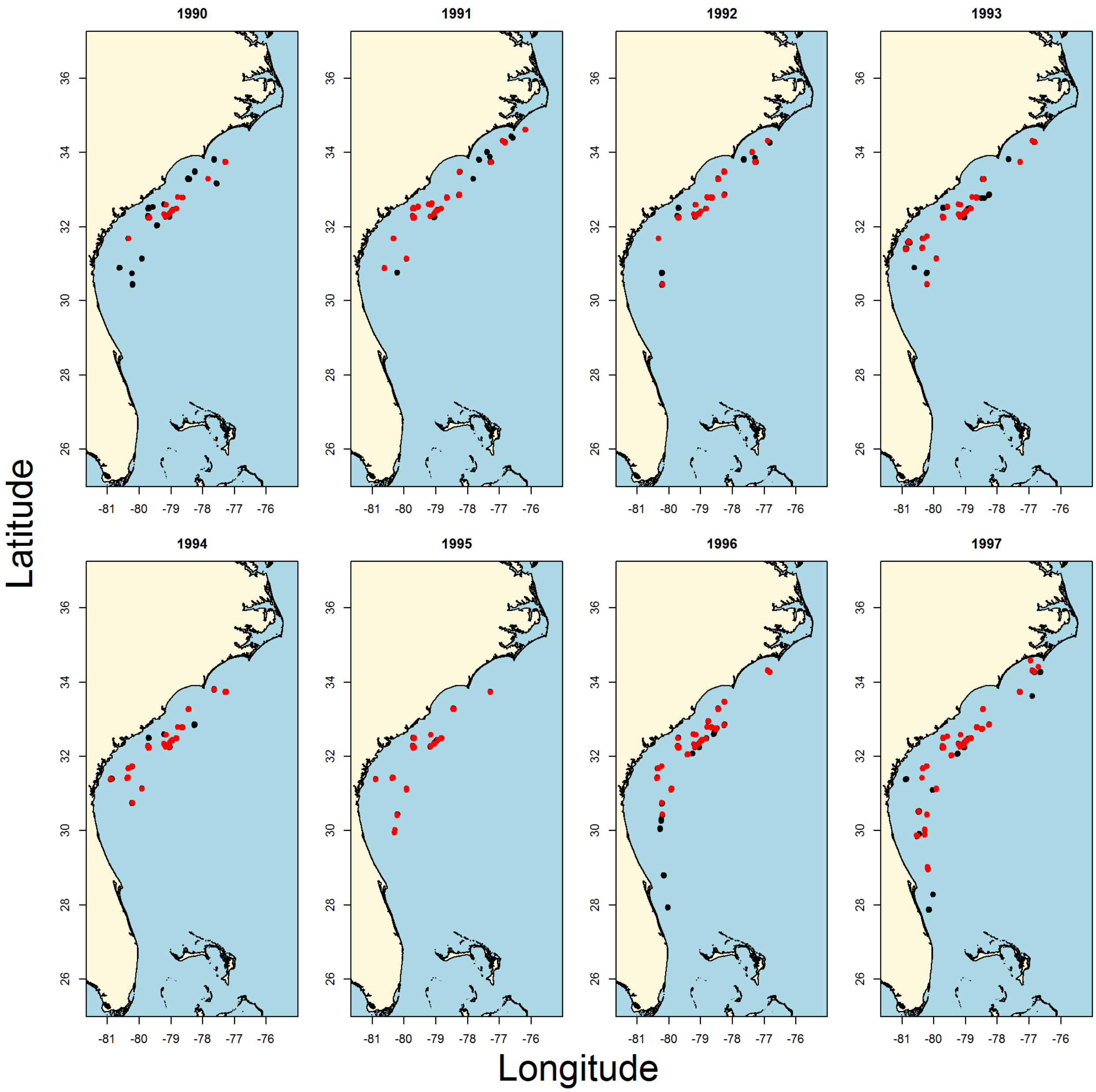
Table 9. Results of AIC selection using forward selection.

Step	Model	Variable	Sub-Model	AIC	Difference
	GTZINB			23110	-1210.30
1	ZINB1ZIAdd4	+Temperature	Zero Inflation	22459	-559.51
2	ZINB2CAdd2	+Depth	Count	22234	-334.21
3	ZINB3CAdd1	+Latitude	Count	22061	-161.21
4	ZINB4CAdd2	+DOY	Count	21957	-57.81
5	ZINB5ZIAdd1	+Year	Zero Inflation	21926	-26.74
6	ZINB6ZIAdd3	+DOY	Zero Inflation	21912	-12.66
7	ZINB7ZIAdd2	+Depth	Zero Inflation	21903	-3.65
8	ZINB8CAdd1	+Temperature	Count	21900	-0.24
9	ZINB9ZIAdd1	+Latitude	Zero Inflation	21899	0.00

Table 10. Gray Triggerfish nominal catch per unit effort (CPUE) and zero-inflated negative binomial (ZINB) standardized CPUE for chevron traps. N = number of included traps, positive = proportion of included collections positive for Gray Triggerfish, CV = coefficient of variation, and normalized = annual index value normalized to its long-term mean to give relative abundance over time.

				Nominal			ZINB Standardized		
Year	**n**	**Positive**	**% Positive**	**CPUE**	**CV**	**Normalized**	**CPUE**	**CV**	**Normalized**
1990	307	34	11.07%	0.225	0.226	0.235	0.149	0.232	0.299
1991	267	121	45.32%	1.371	0.1	1.432	0.729	0.176	1.462
1992	288	83	28.82%	0.663	0.147	0.693	0.565	0.175	1.133
1993	410	118	28.78%	0.727	0.114	0.759	0.384	0.111	0.770
1994	398	153	38.44%	1.121	0.104	1.171	0.532	0.114	1.067
1995	334	150	44.91%	1.967	0.128	2.055	0.607	0.119	1.217
1996	376	144	38.30%	1.939	0.148	2.026	0.917	0.116	1.838
1997	394	161	40.86%	1.779	0.124	1.859	0.756	0.104	1.515
1998	445	113	25.39%	1.108	0.143	1.158	0.816	0.149	1.636
1999	216	55	25.46%	0.833	0.189	0.871	0.378	0.170	0.759
2000	292	82	28.08%	0.726	0.189	0.759	0.354	0.272	0.710
2001	245	82	33.47%	0.918	0.122	0.96	0.421	0.143	0.844
2002	244	98	40.16%	1.311	0.123	1.37	0.713	0.195	1.430
2003	225	29	12.89%	0.236	0.204	0.246	0.254	0.281	0.508
2004	290	74	25.52%	0.634	0.151	0.663	0.570	0.152	1.143
2005	303	92	30.36%	1.083	0.152	1.131	0.412	0.126	0.826
2006	293	66	22.53%	0.512	0.162	0.535	0.296	0.156	0.594
2007	336	105	31.25%	0.932	0.172	0.973	0.442	0.157	0.885
2008	303	65	21.45%	1.066	0.193	1.114	0.435	0.175	0.873
2009	396	80	20.20%	0.649	0.175	0.678	0.310	0.161	0.621
2010	618	133	21.52%	0.524	0.127	0.548	0.287	0.135	0.576
2011	688	141	20.49%	0.757	0.13	0.791	0.399	0.136	0.799
2012	1133	323	28.51%	0.954	0.088	0.997	0.618	0.093	1.240
2013	1329	357	26.86%	0.933	0.077	0.975	0.625	0.092	1.254

Figures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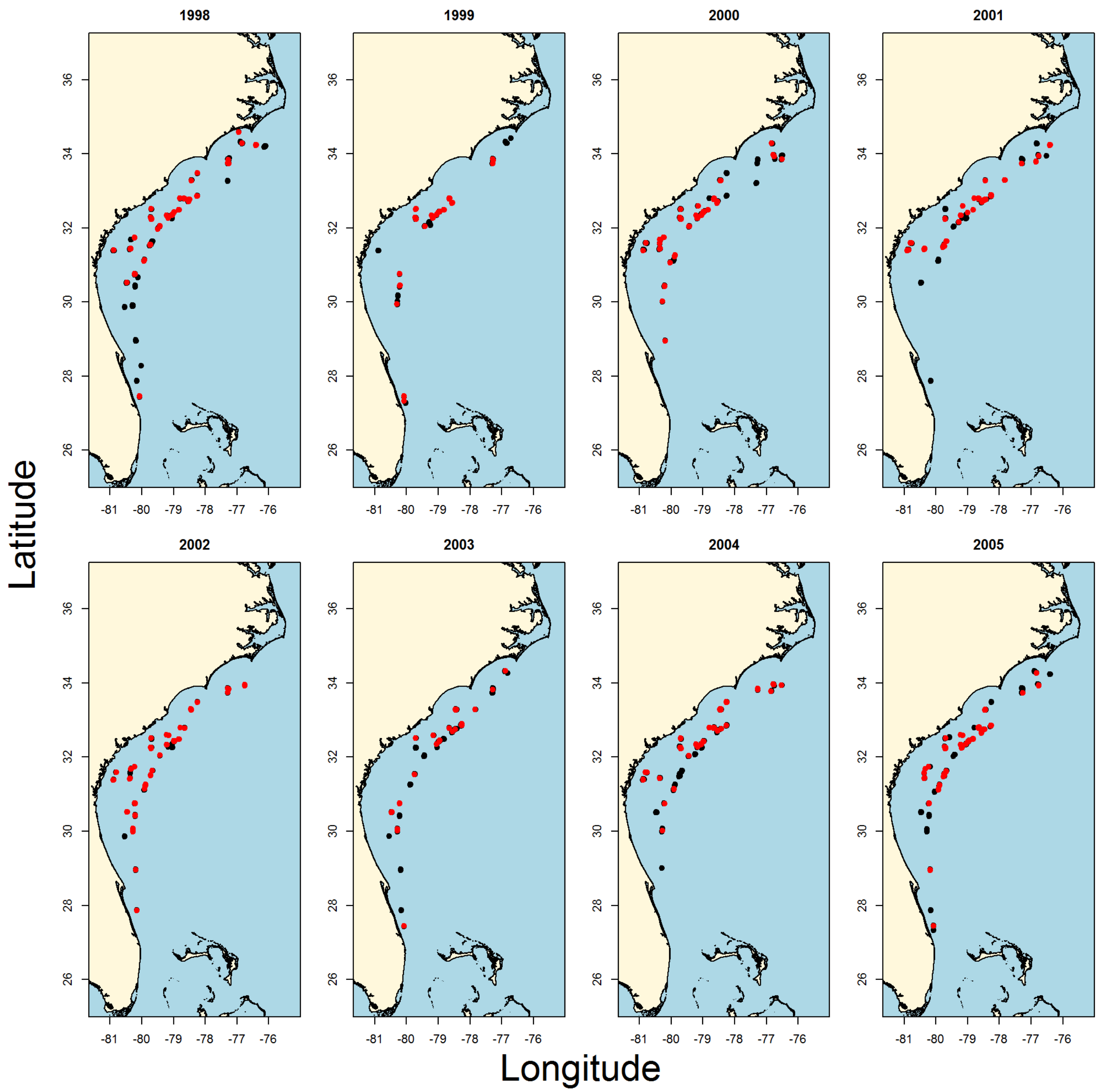
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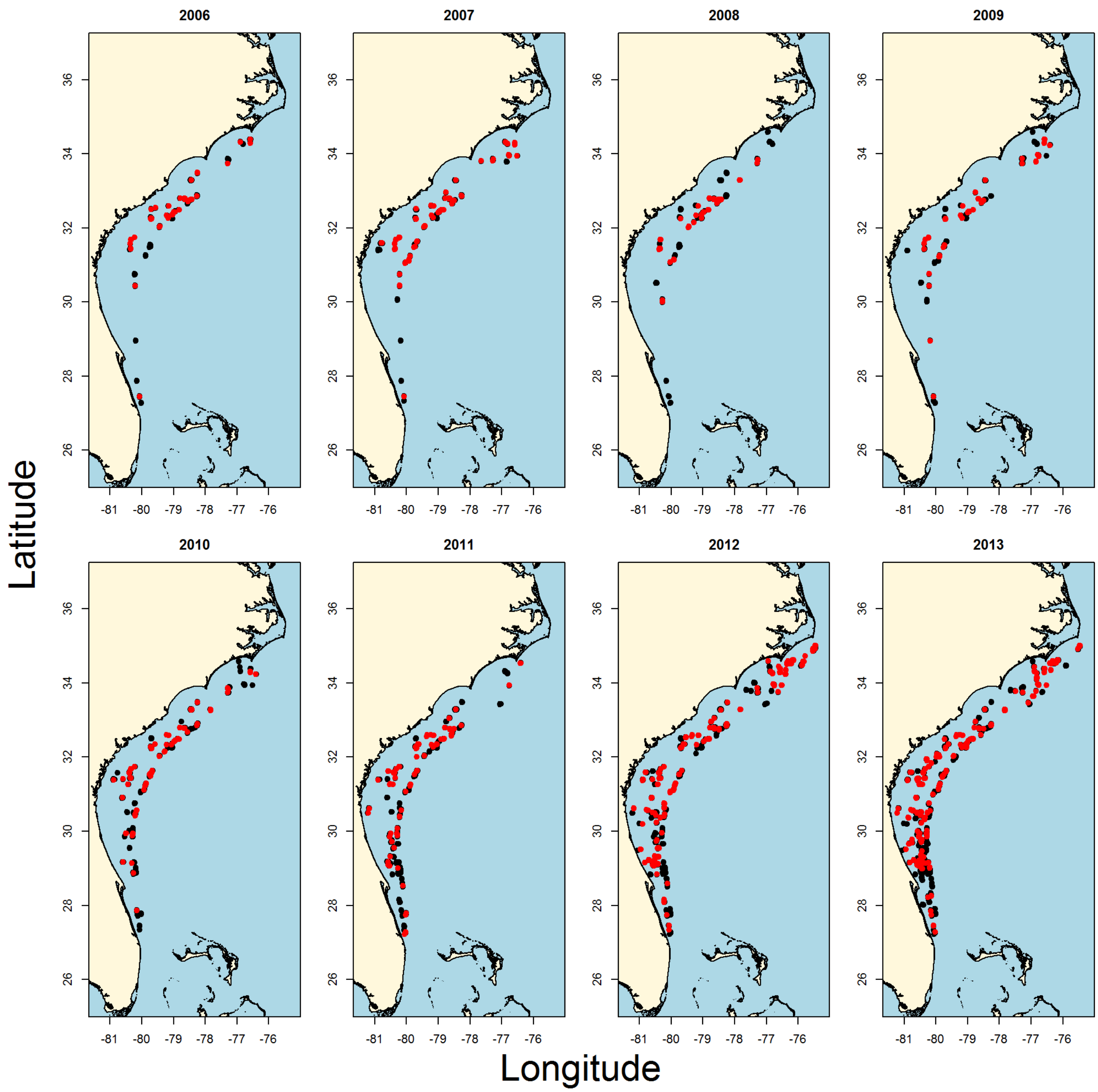

Figure 1: Progression of the spatial coverage of monitoring chevron trap deployments by the Southeast Reef Fish Survey since the initial year using chevron traps to monitor fish on live/hard bottom. Red indicates stations at which Gray Triggerfish were collected in a given year. Note that each symbol may represent multiple sampling events. CTDs were deployed with each trap set, but not pictured here.

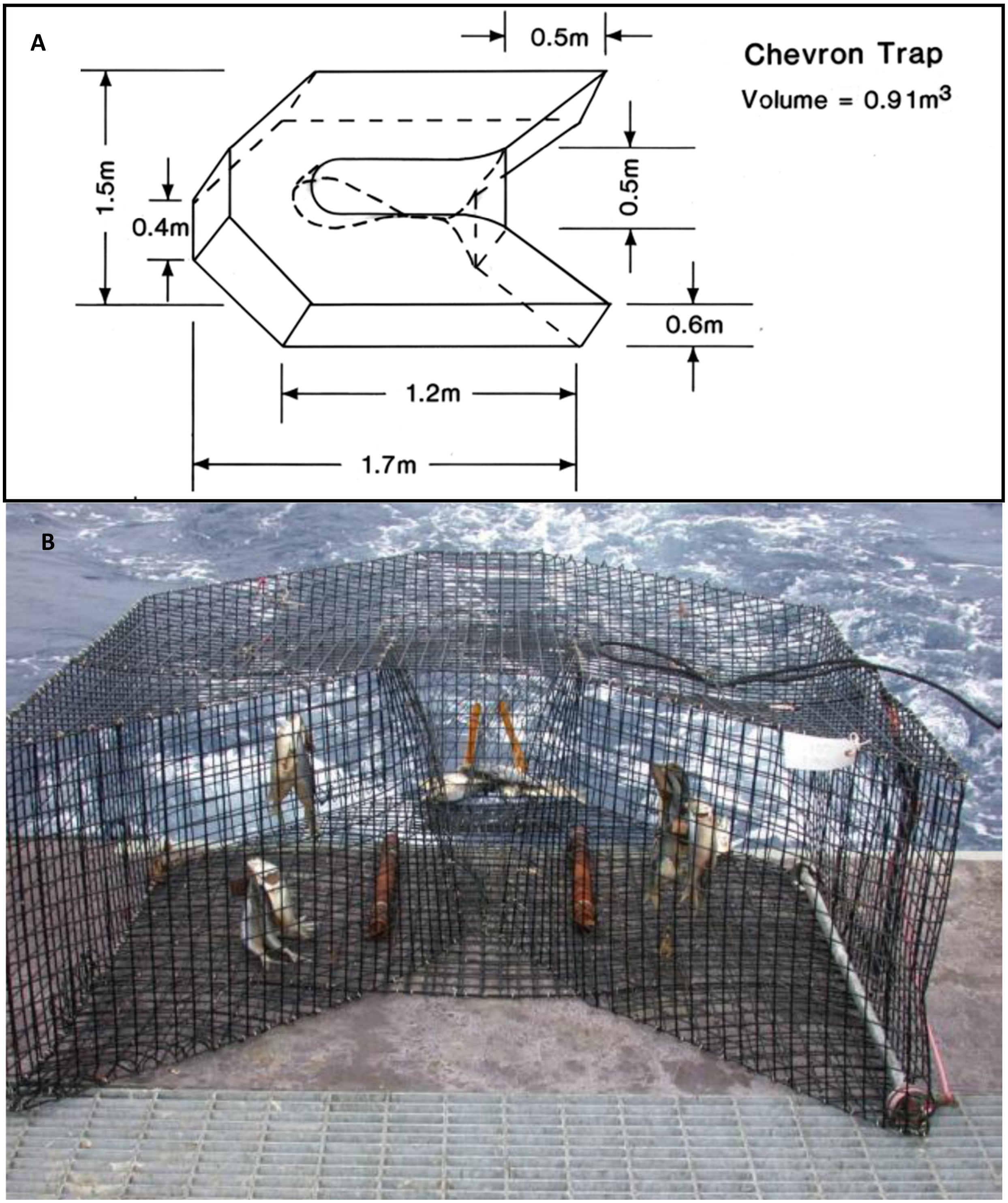

Figure 2. Chevron traps used by SERFS for monitoring reef fish. A. Diagram with dimensions. B. Chevron trap ready for deployment baited with clupeids. Iron sashes attached to the bottom weigh the trap down and help maintain the proper orientation of the trap on the bottom.

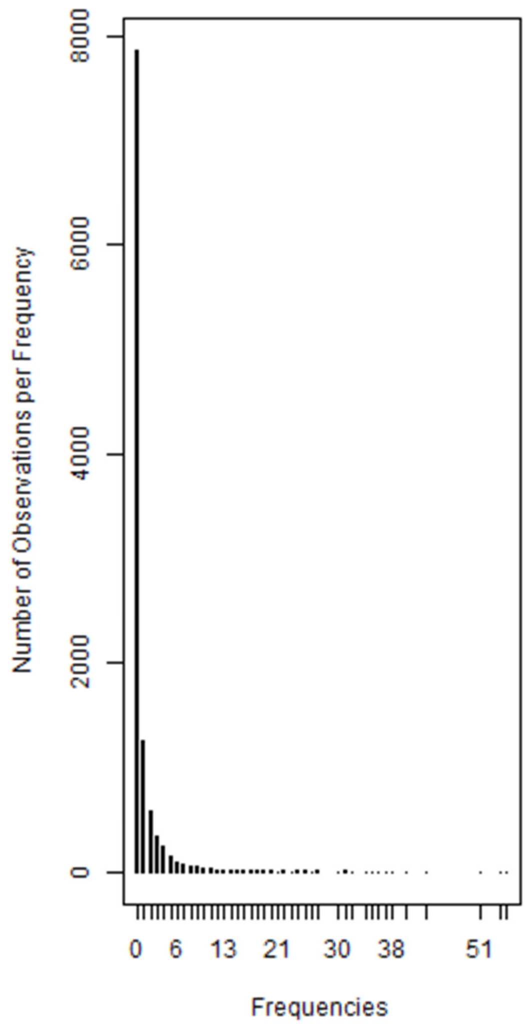

Figure 3. Frequency of occurrence of chevron traps with a given catch of Gray Triggerfish.

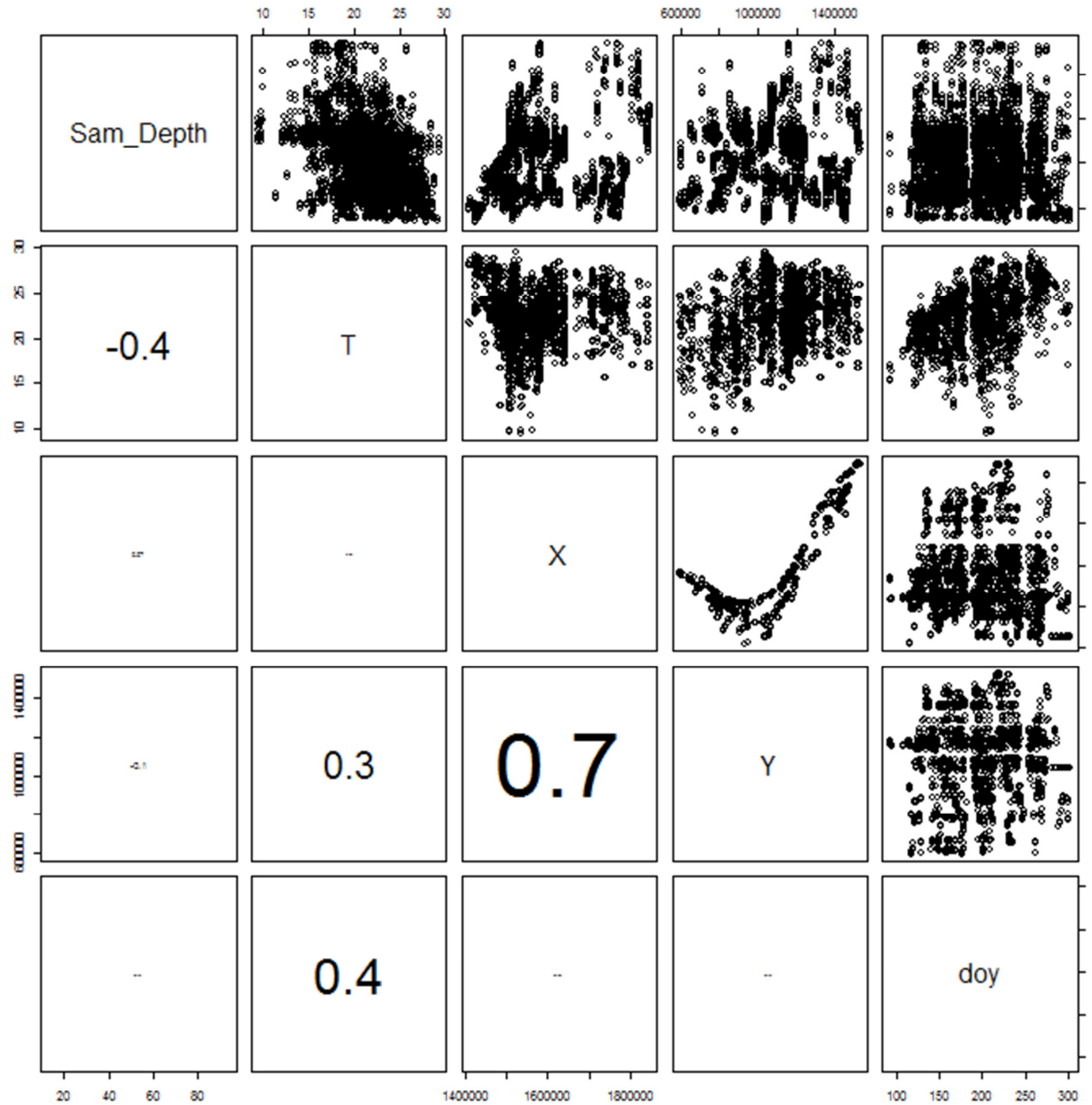

Figure 4. Pairs plot of correlation between considered continuous covariates. Diagonal provides the variable name, lower triangle provides the correlation coefficient estimates, and upper triangle provides scatter plots of the raw data. Sam_Depth=depth in meters; T=bottom temperature in ^{o}C; X=longitude in m, Y=latitude in m; and doy=day of year.

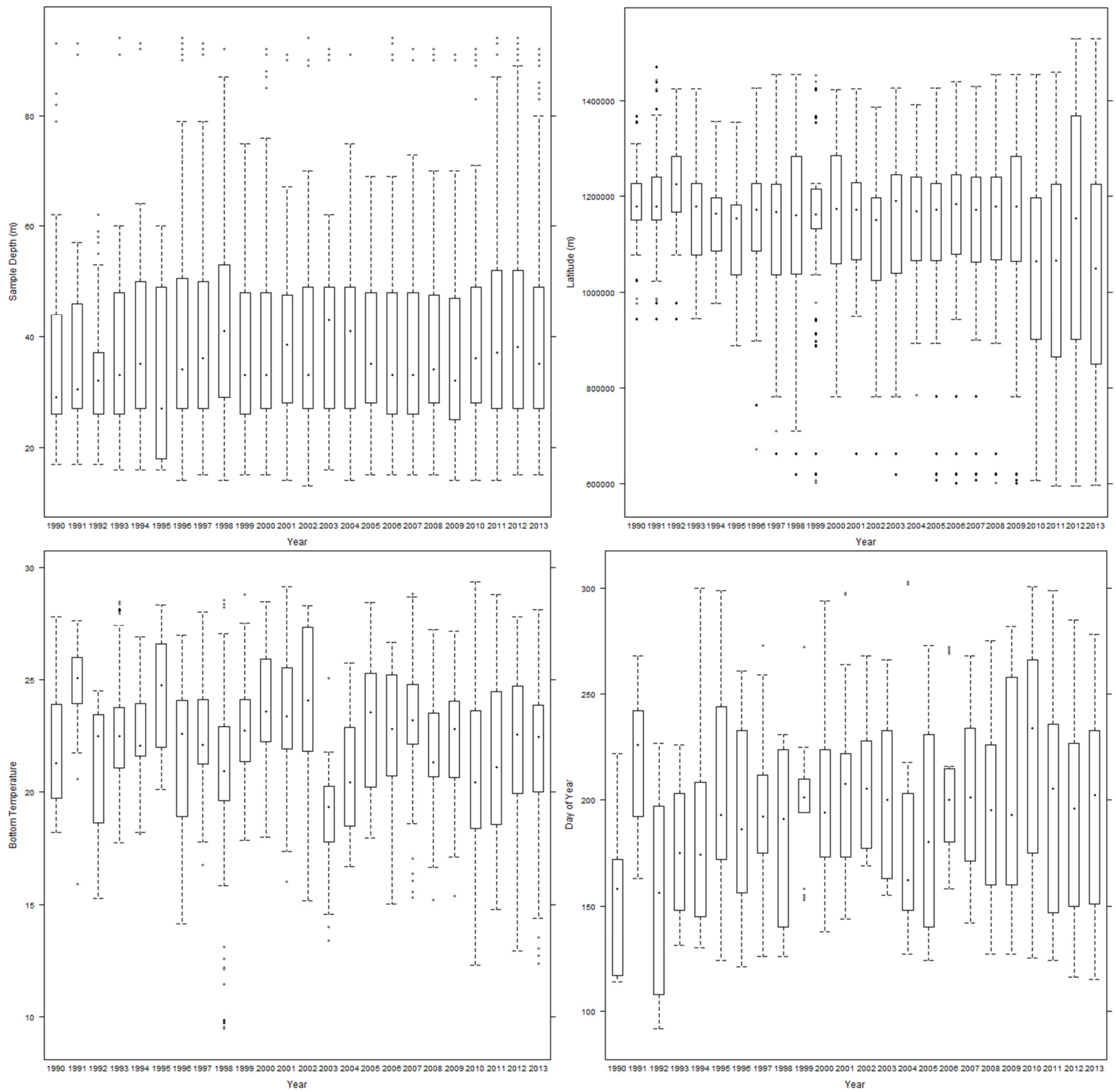

Figure 5. Box plot of depth (top left), latitude (top right), bottom temperature (bottom left), and day of year (bottom right) as a function of year.

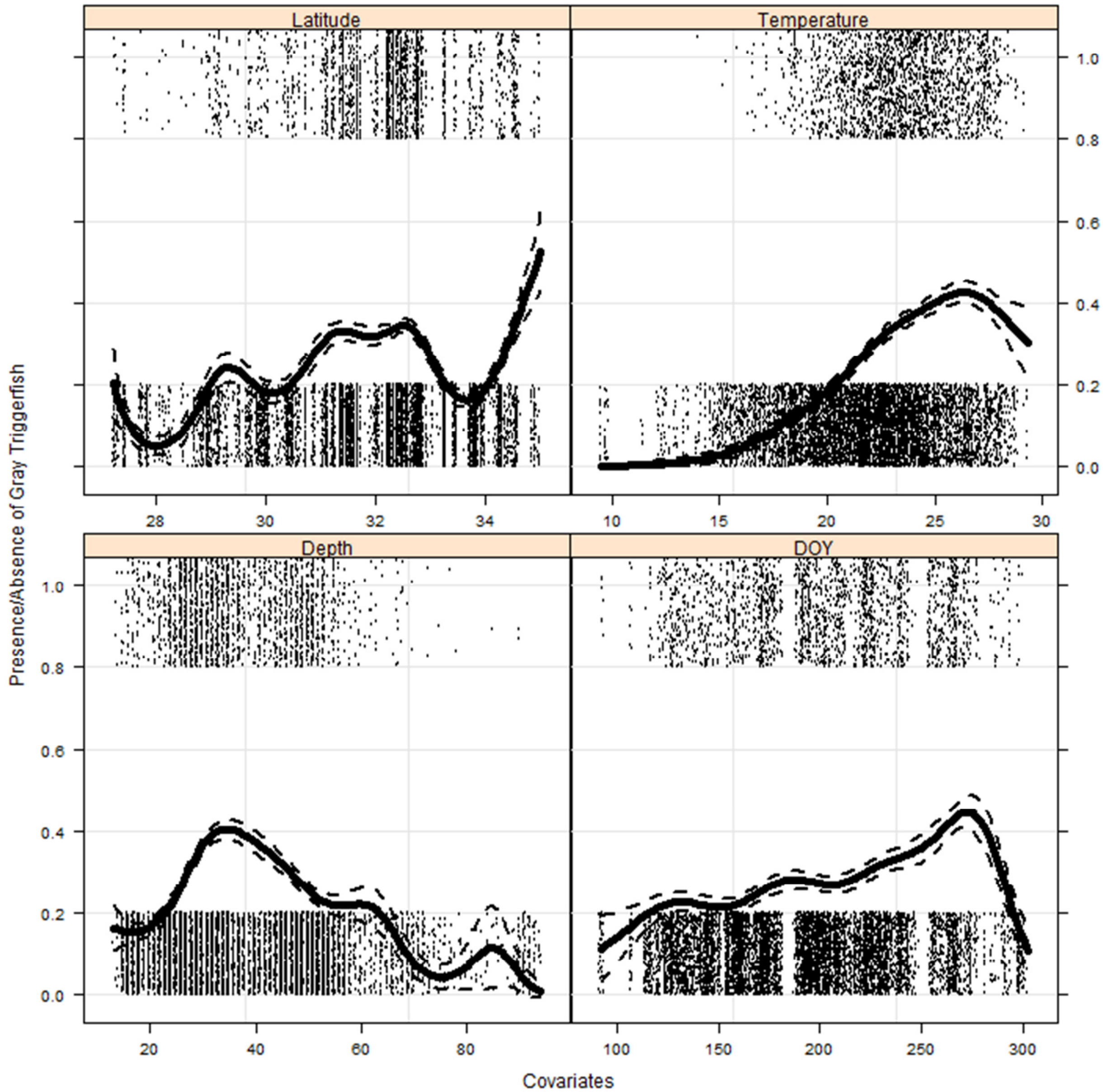

Figure 6. Presence (1) and absence (0) of Gray Triggerfish with respect to the considered covariates, latitude (°N), depth (m), bottom temperature (^{o}C) and day of year (DOY). The raw presence/absence data has been jittered in the figure. The solid black line represents a fitted GAM to the presence/absence data with respect to a given covariate. Dashed black lines represent 95% confidence intervals around the GAM fit.

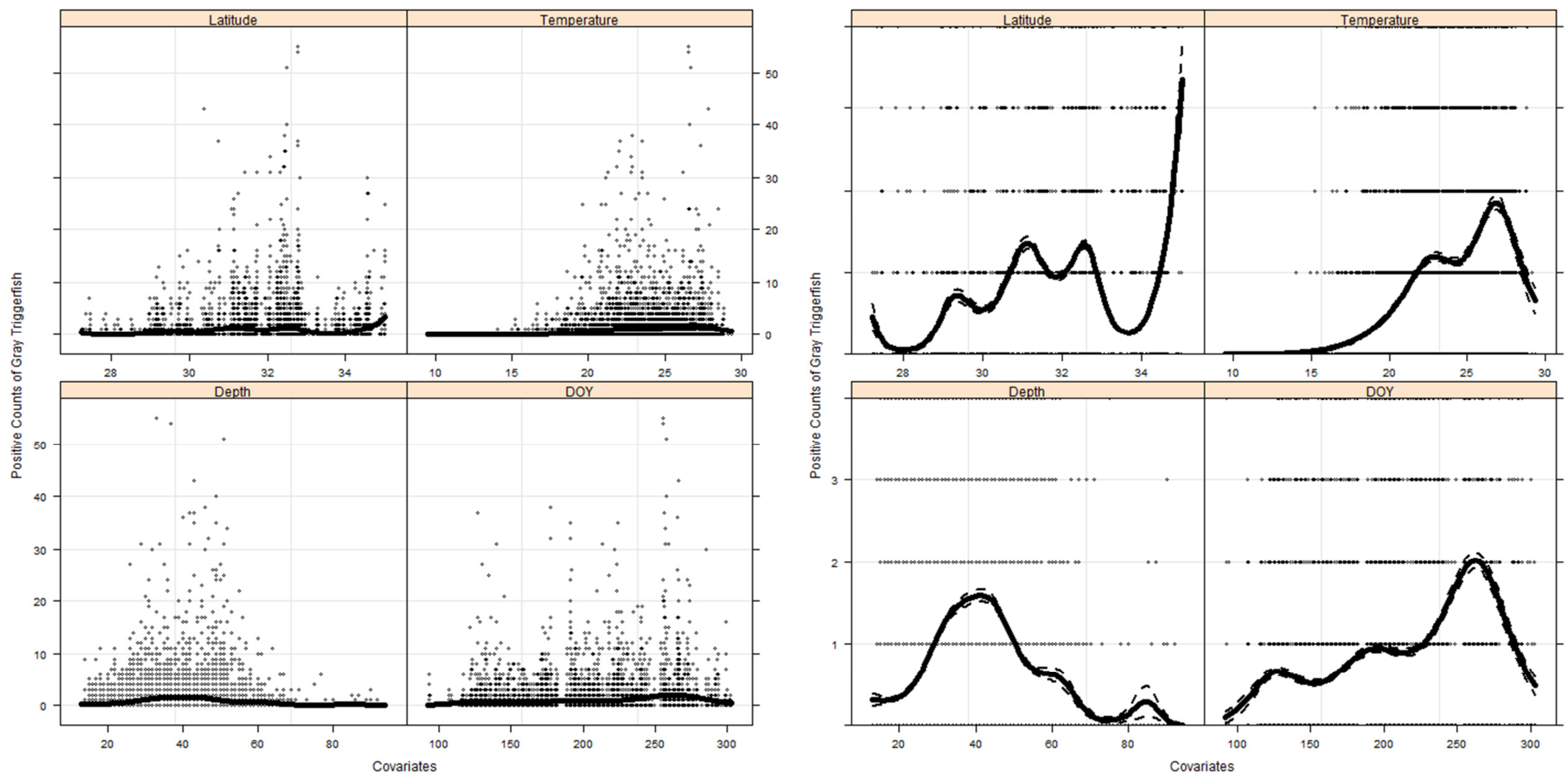

Figure 7. Catch of gray triggerfish with respect to the considered covariates, latitude (°N), depth (m), and day of year (DOY). The left panel has an unrestricted y-axis that shows the full catch distribution of Gray Triggerfish. The right panel restricts the y-axis to the range of the GAM model fits to show better detail of the GAM fits. Sold black line represents a fitted GAM to the catch data with respect to a given covariate. Dashed black lines represent 95% confidence intervals about the GAM fit.

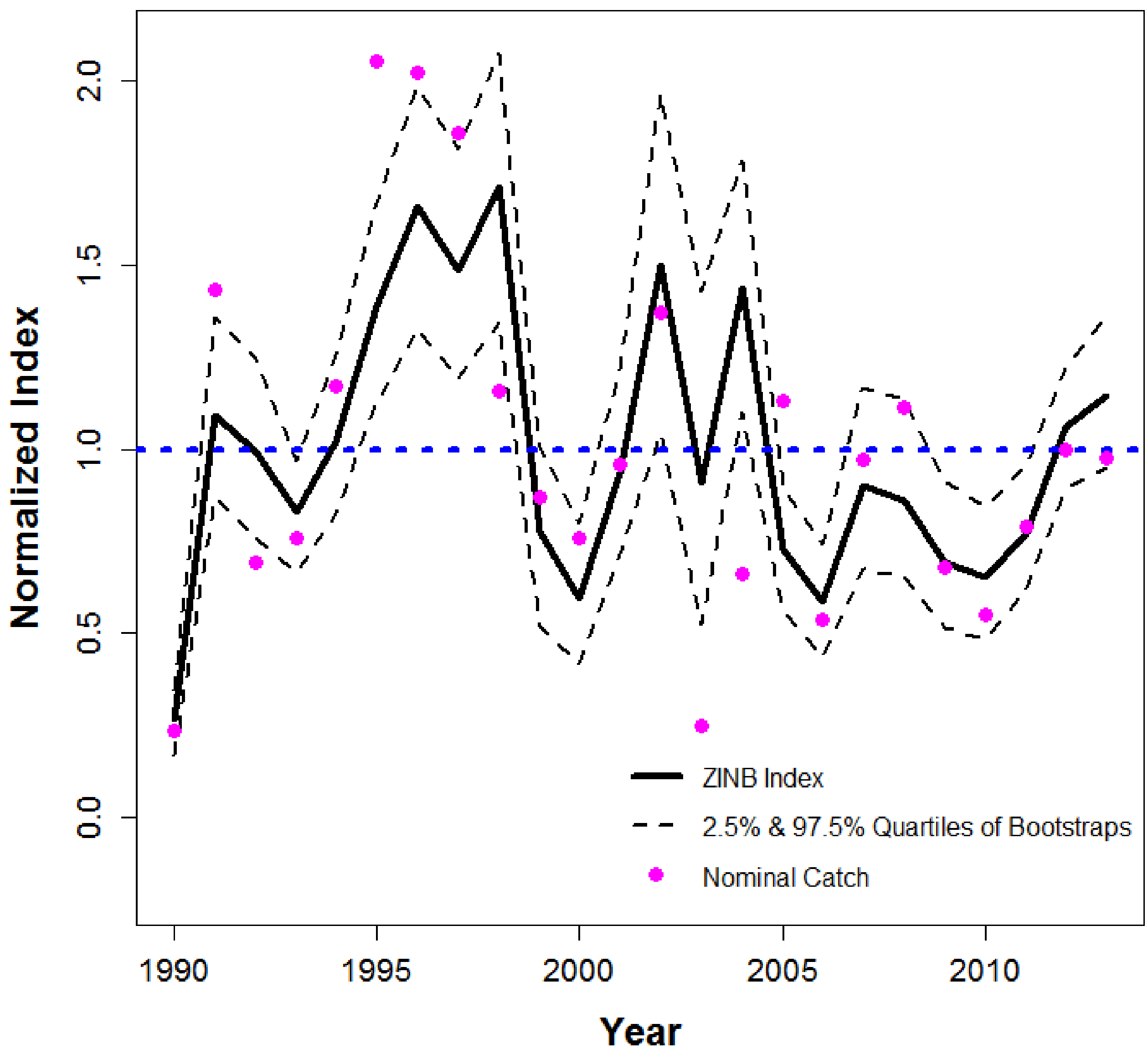

Figure 8. Gray triggerfish index of relative abundance for chevron traps. Nominal catch and zero-inflated negative binomial (ZINB) standardized catch normalized to each index's long-term mean to provide relative abundance.

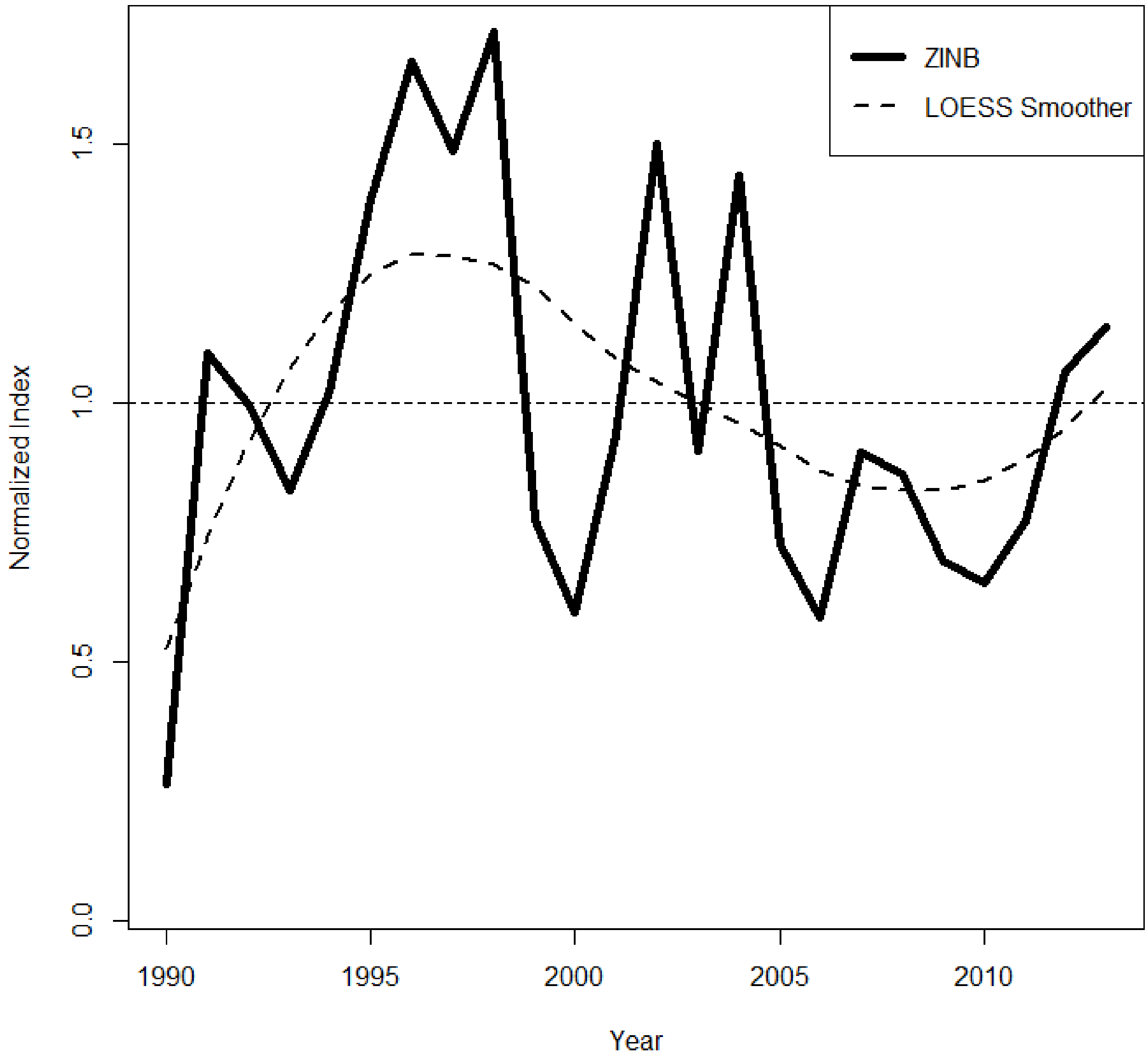

Figure 9. ZINB index of relative abundance for Gray Triggerfish based on the best fit ZINB selected by the Bayesian information criterion (BIC). Heavy dashed-line represents locally-weight scatterplot smoothing (LOESS smoother) that has been added to the plot to aid visual interpretation of the abundance trends. All index values were normalized to the series' mean prior to plotting.

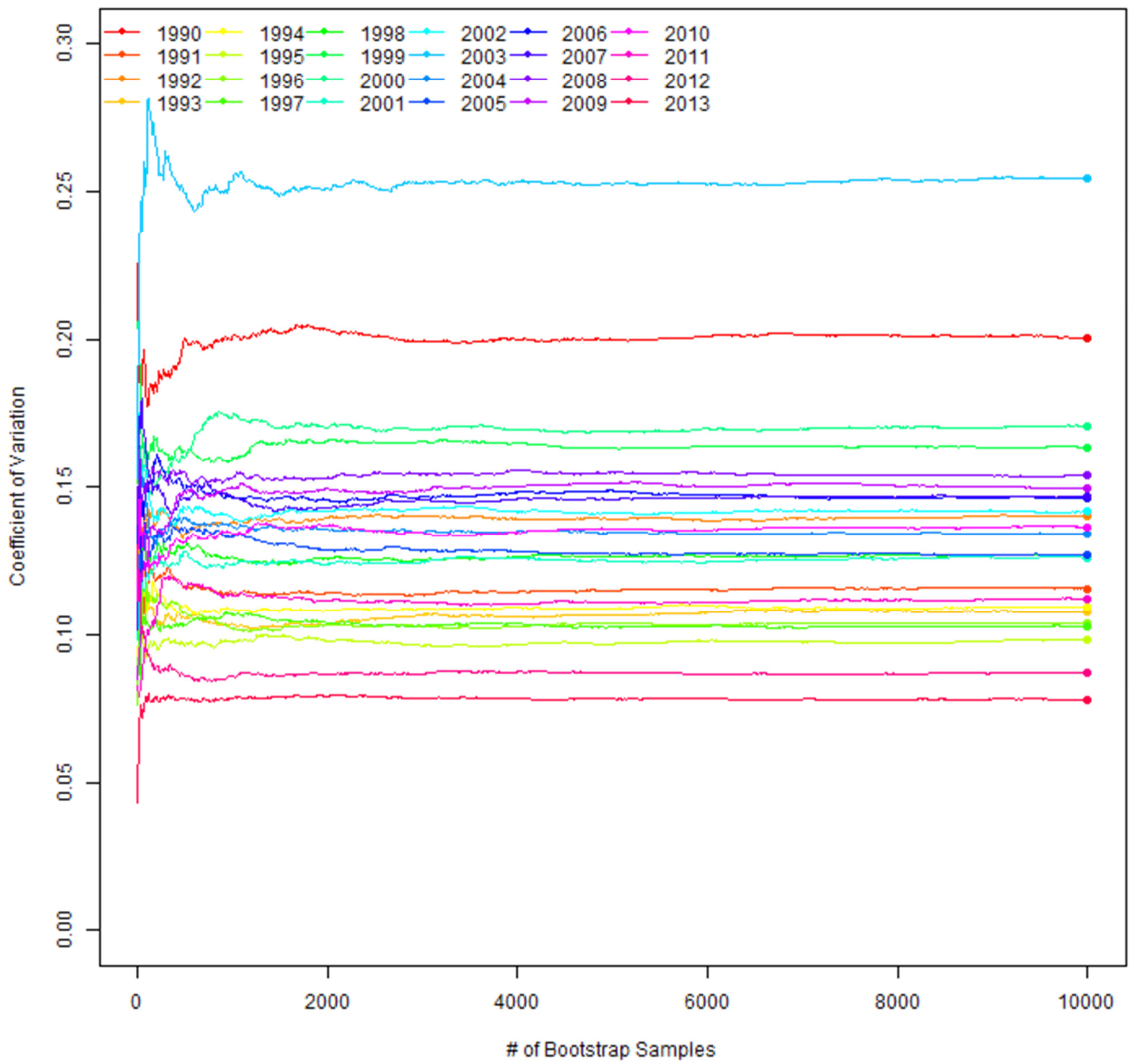

Figure 10. Bootstrap diagnostic plots used to determine if coefficient of variation (CV) estimates stabilized over the number of bootstrap iterations run.

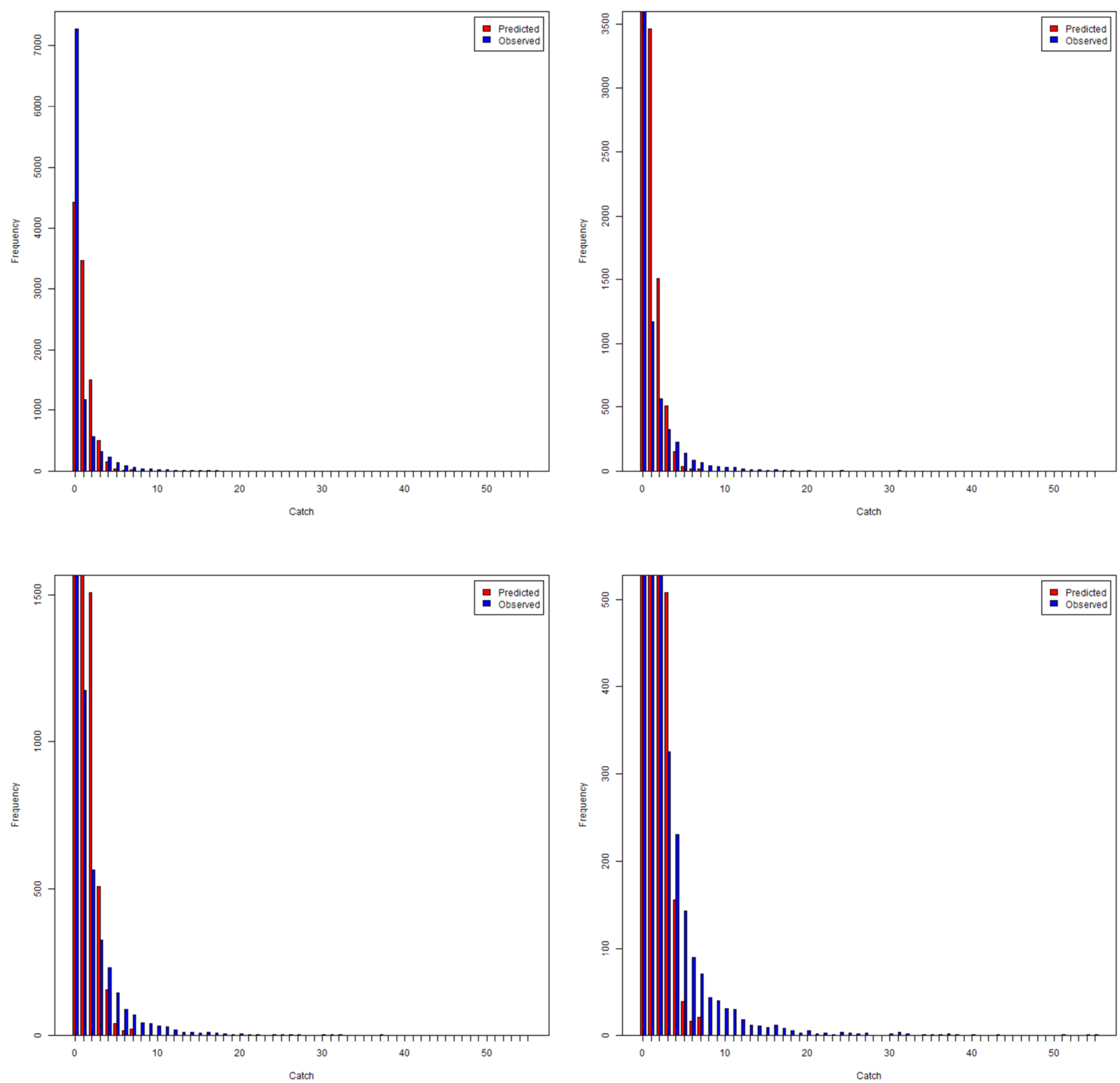

Figure 11. Frequency of traps observed (Observed) with a given catch of Gray Triggerfish or predicted by the ZINB (Predicted). Plots represent the same data, with the y-axis truncated to better resolve low frequencies.

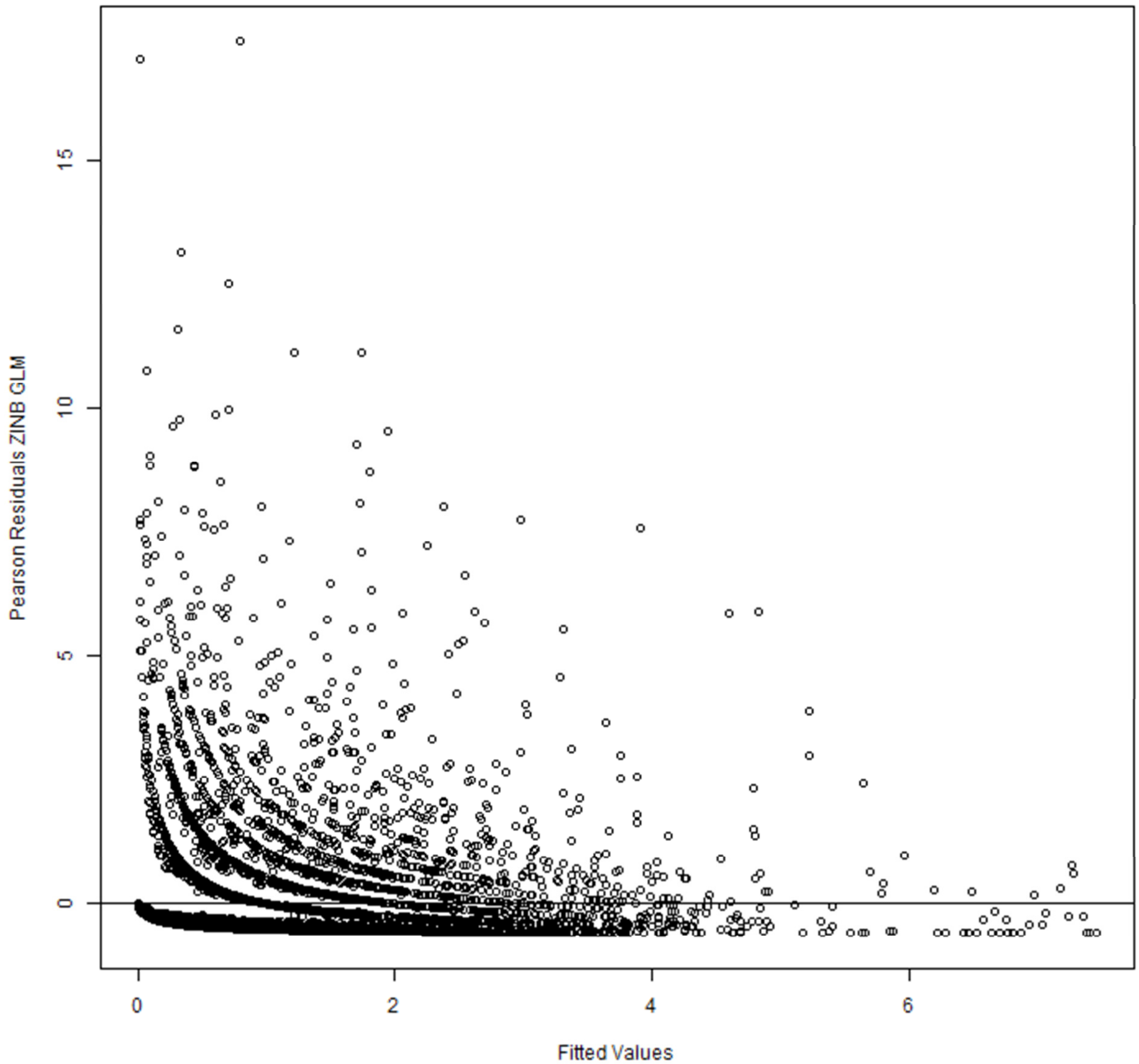

Figure 12. Pearson residuals versus fitted values for the final ZINB model.

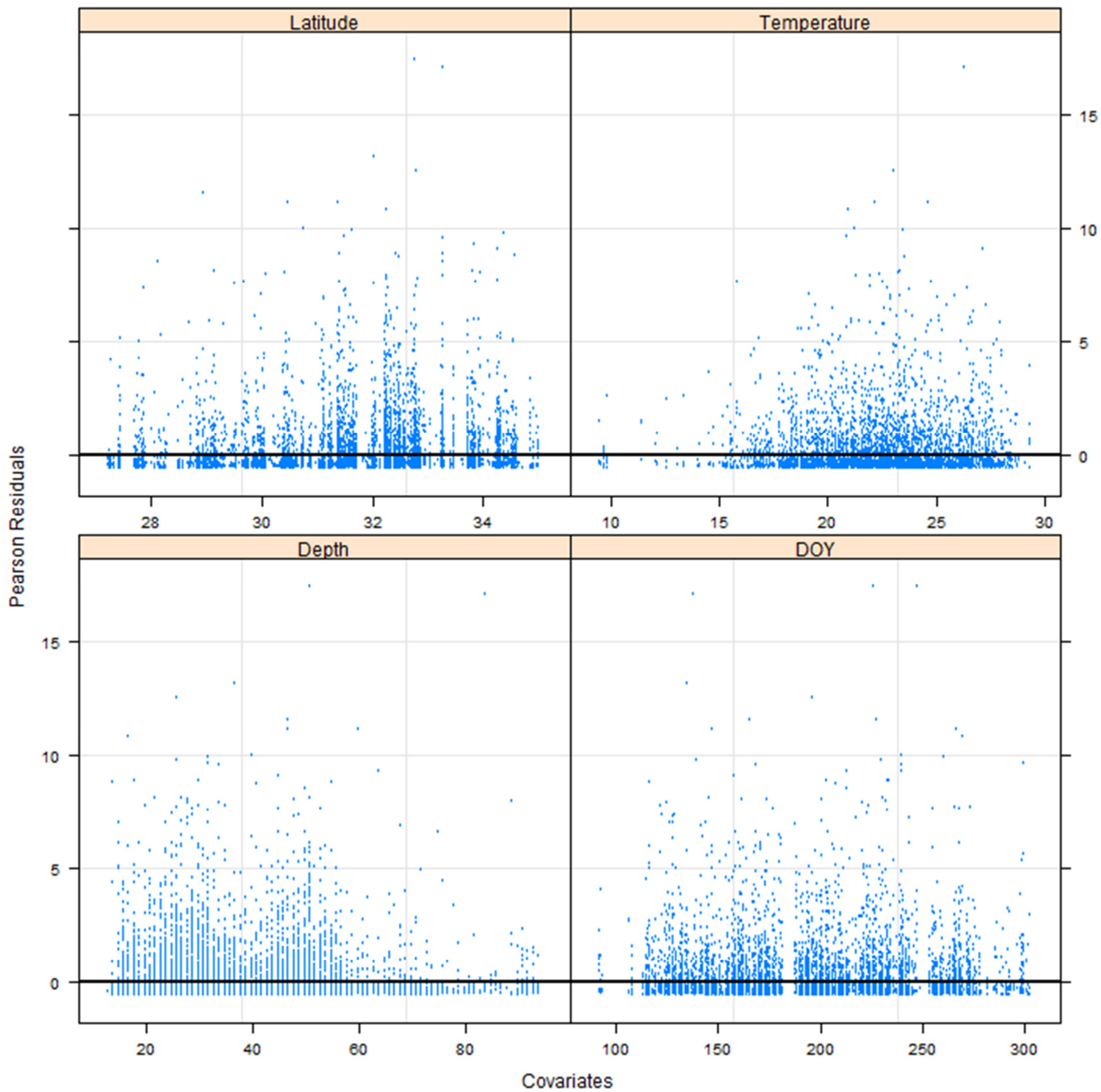

Figure 13. Pearson residuals versus covariates included in the final ZINB model.

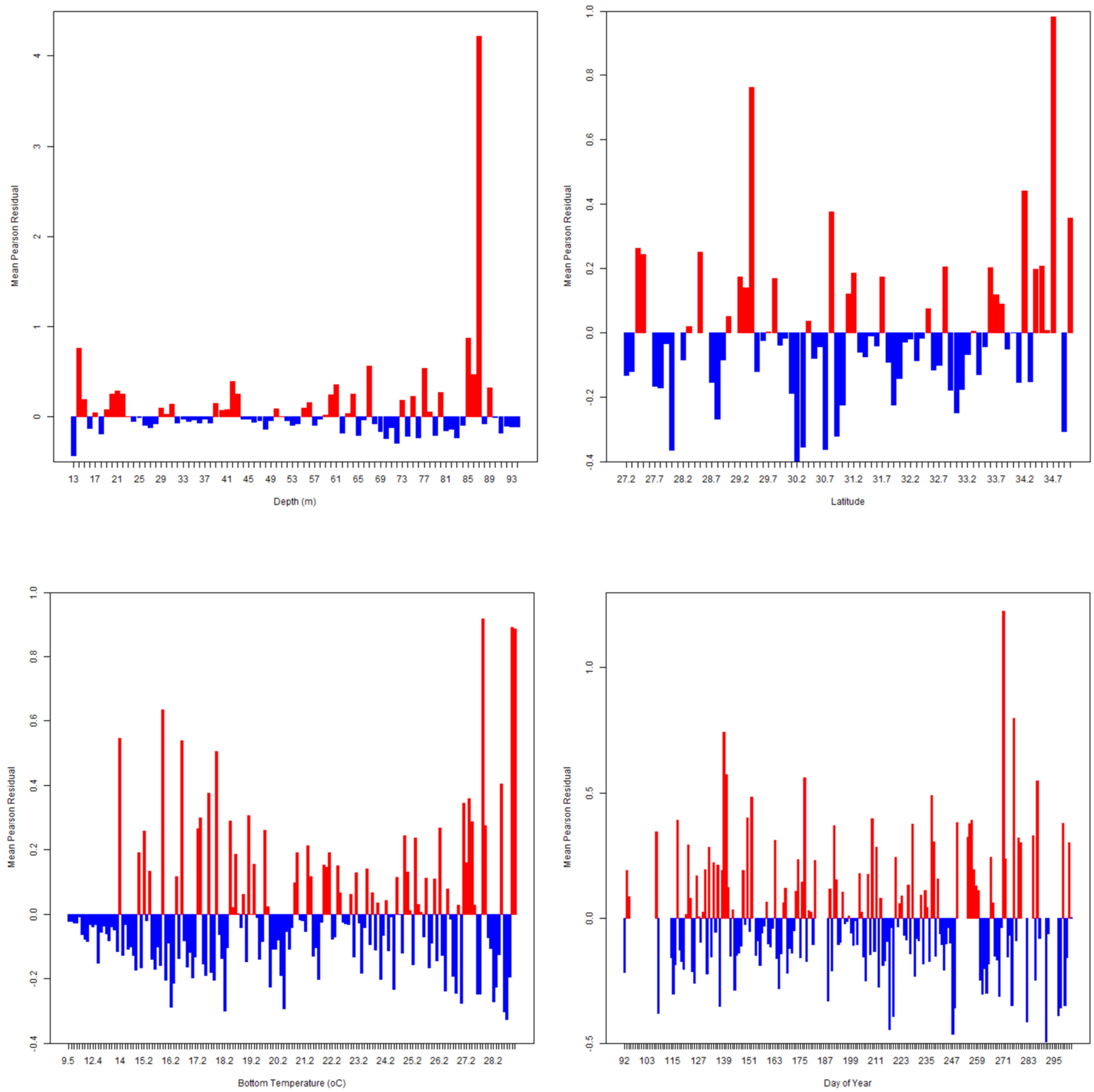

Figure 14. Mean Pearson residual versus included covariates for the final ZINB model.

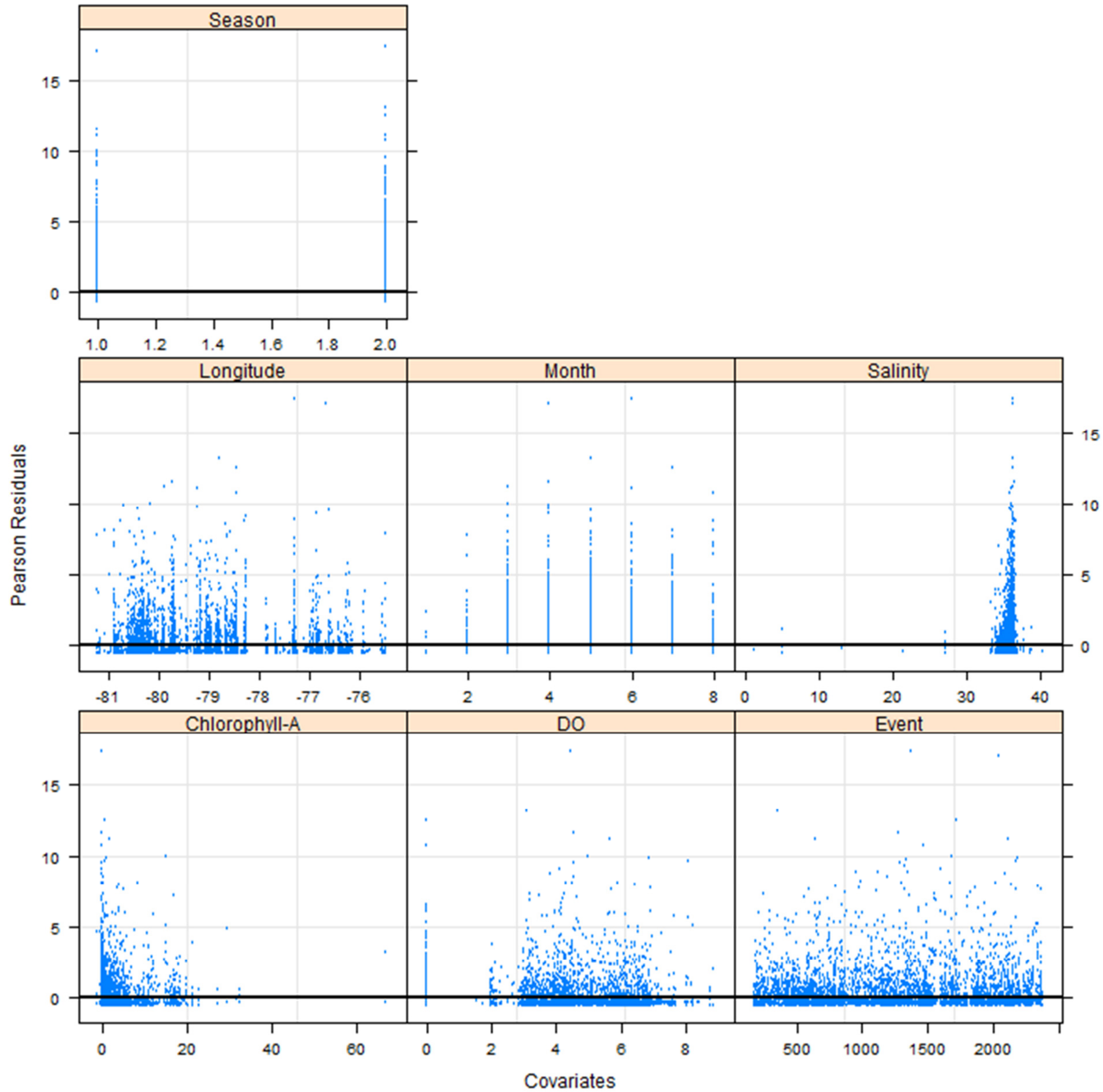

Figure 15. Pearson residuals versus covariates excluded from the final ZINB model.

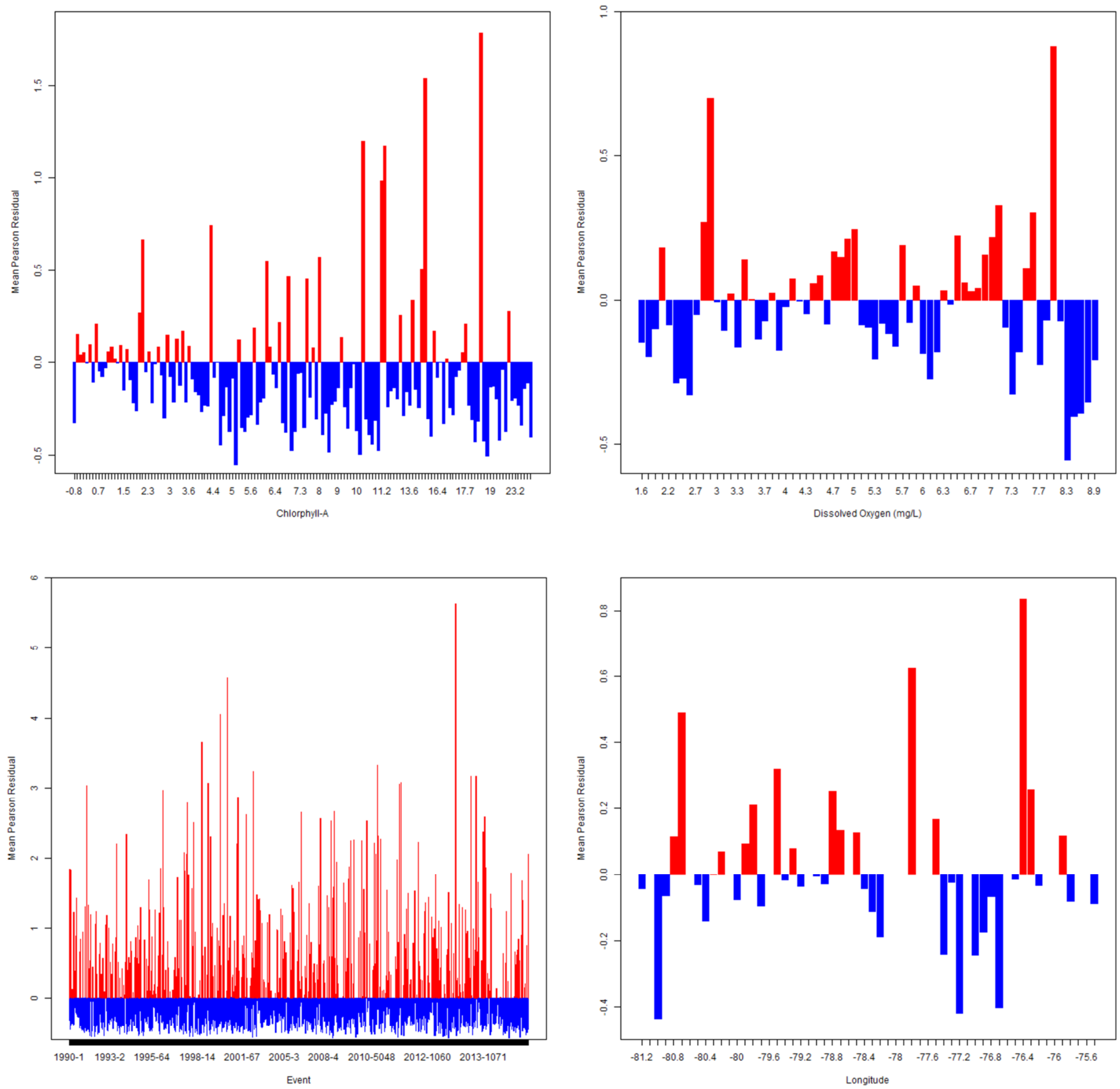

Figure 16. Mean Pearson residuals versus covariates excluded from the final ZINB model.

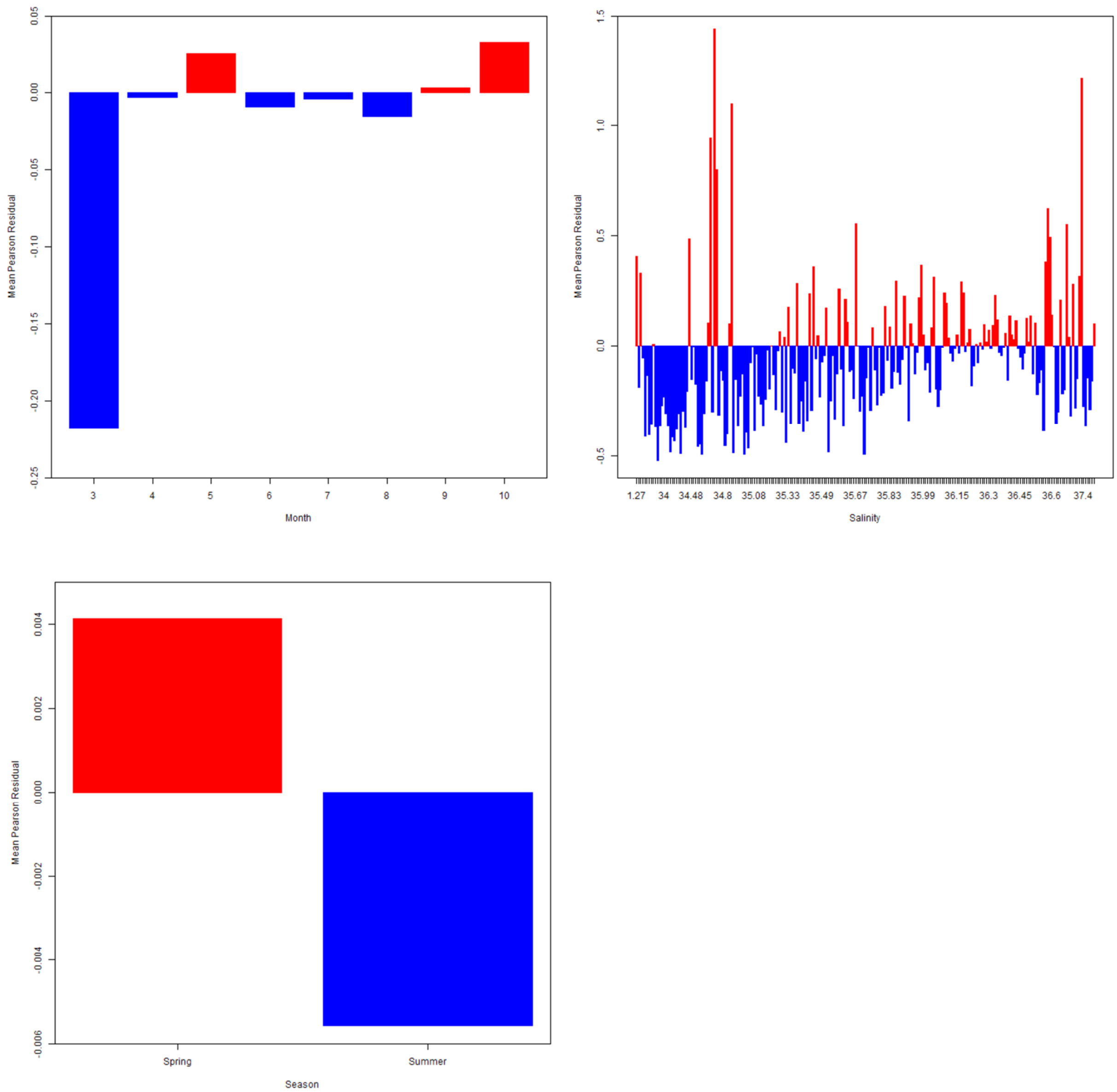

Figure 16 (cont). Mean Pearson residuals versus covariates excluded from the final ZINB model.

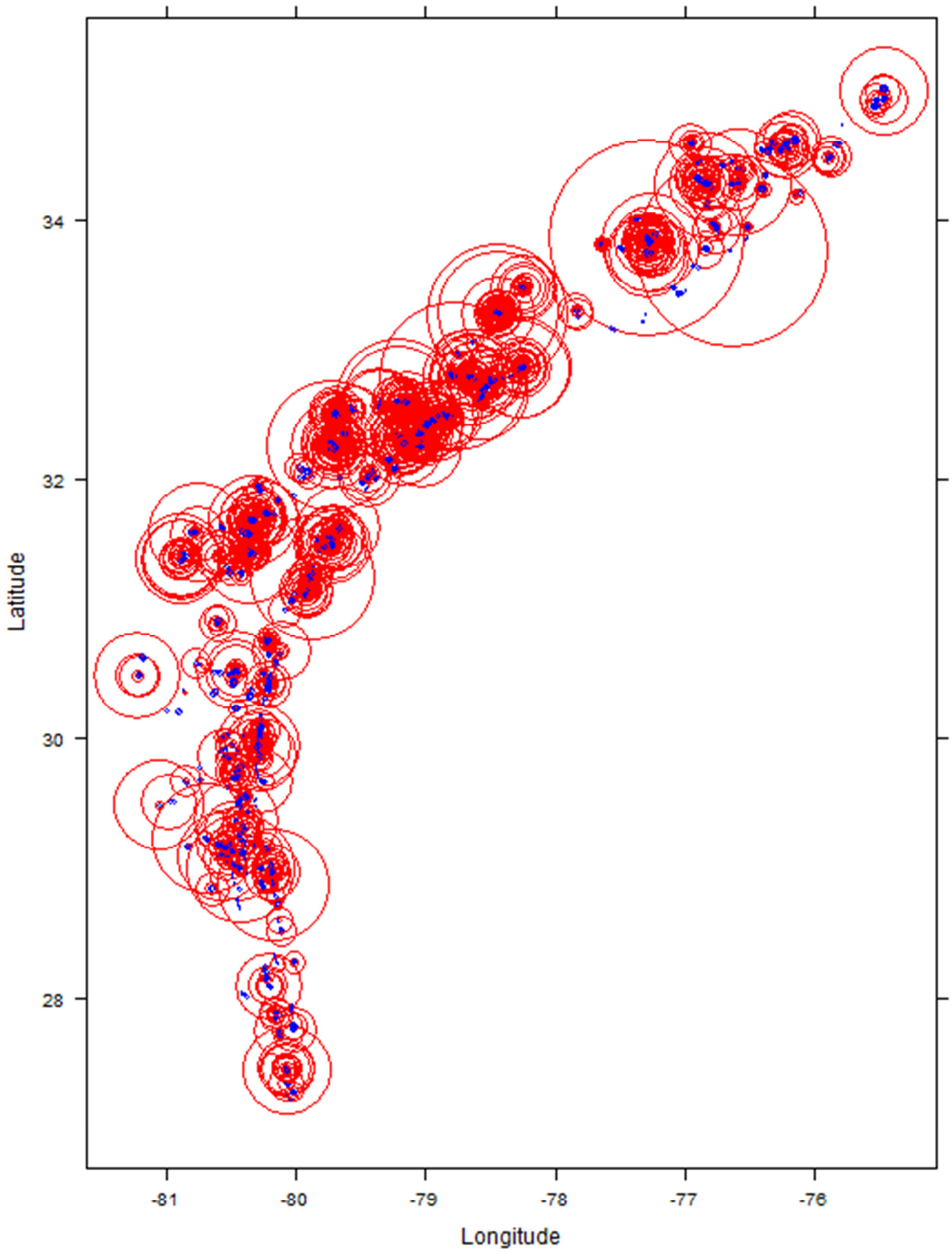

Figure 17. Spatial distribution of Pearson residuals. Red circles indicate positive Pearson residuals and blue circles represent negative Pearson residuals. Size of the circle is indicative of the magnitude of the residual with larger circles corresponding to larger Pearson residual values.

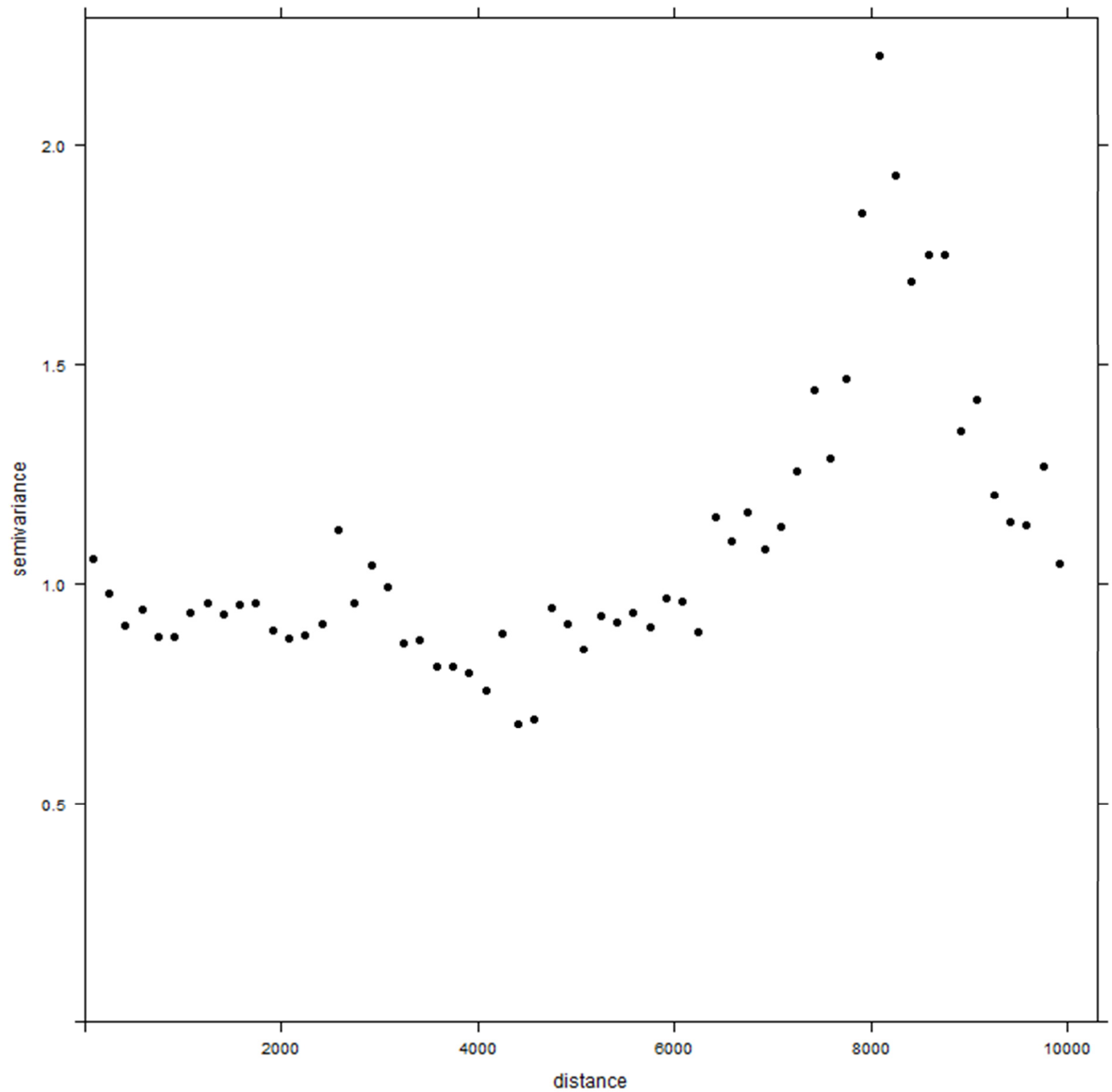

Figure 18. Sample variogram of Pearson residuals. The sample variogram is limited to 10,000 m (10 km).

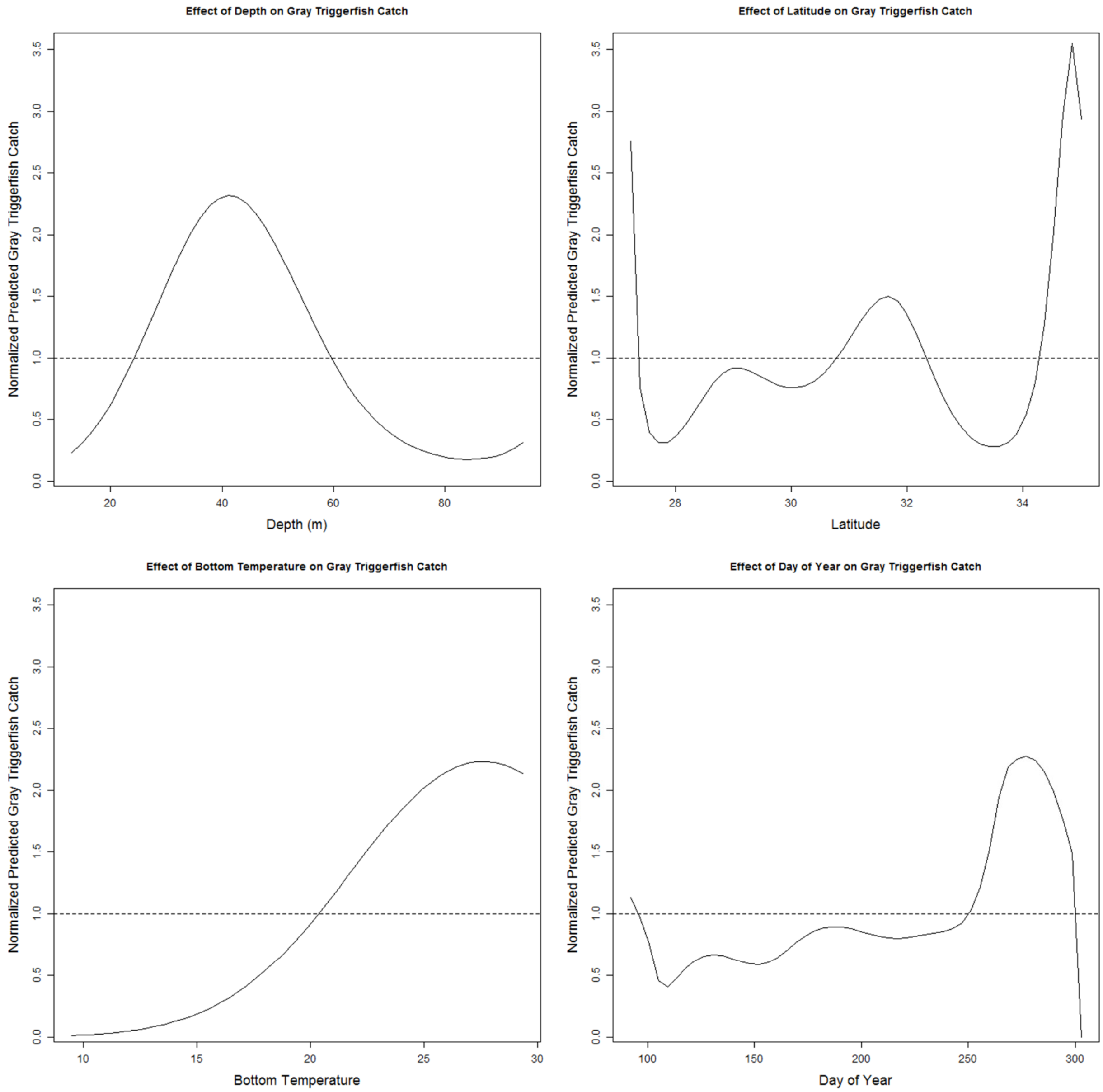

Figure 19. Covariate effects on predicted gray triggerfish catch.

Addendum Figures

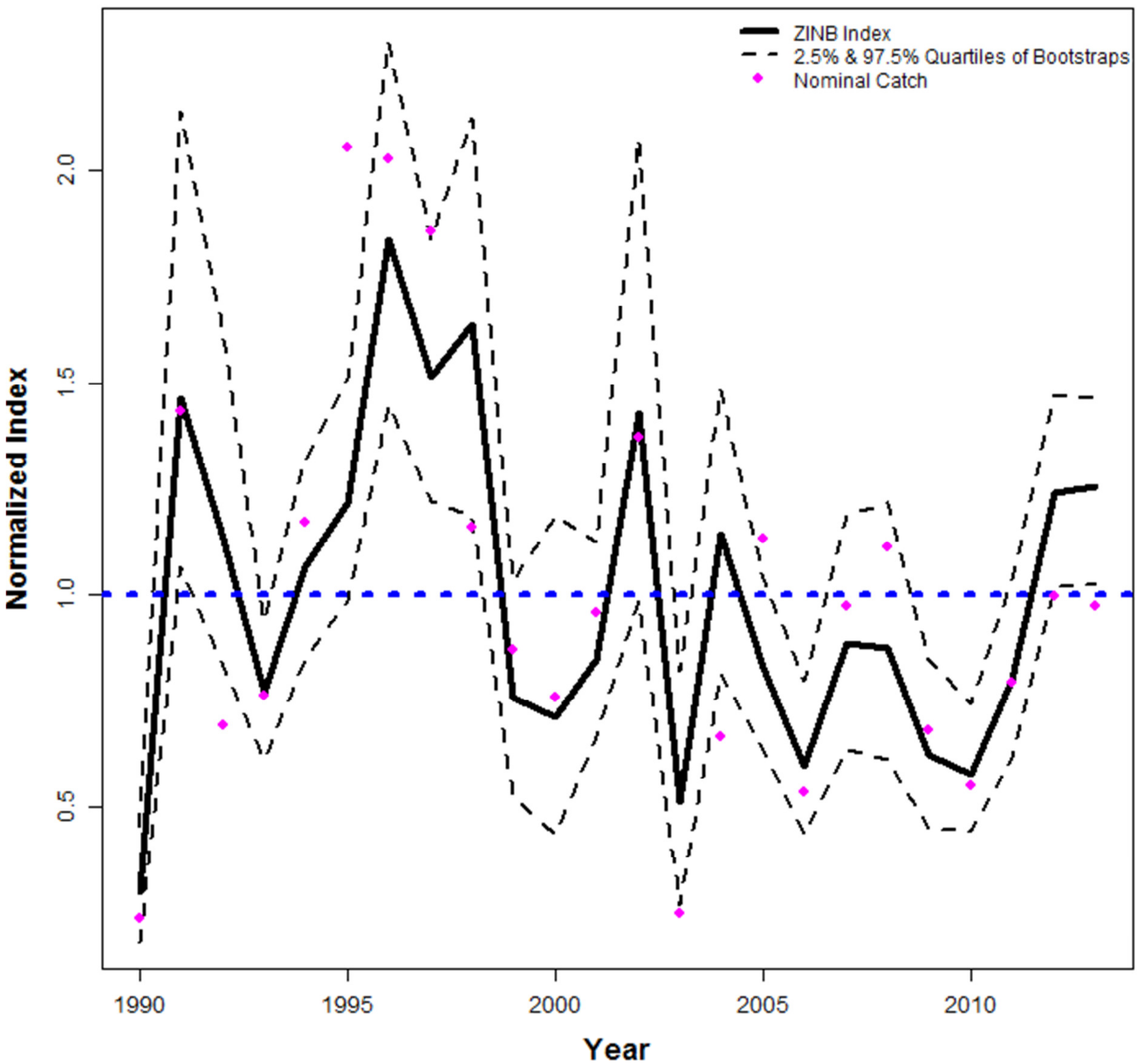

Figure 20. Gray Triggerfish index of relative abundance for chevron traps. Nominal catch and Zero-inflated negative binomial (ZINB) standardized catch normalized to each index's long-term mean to provide relative abundance.

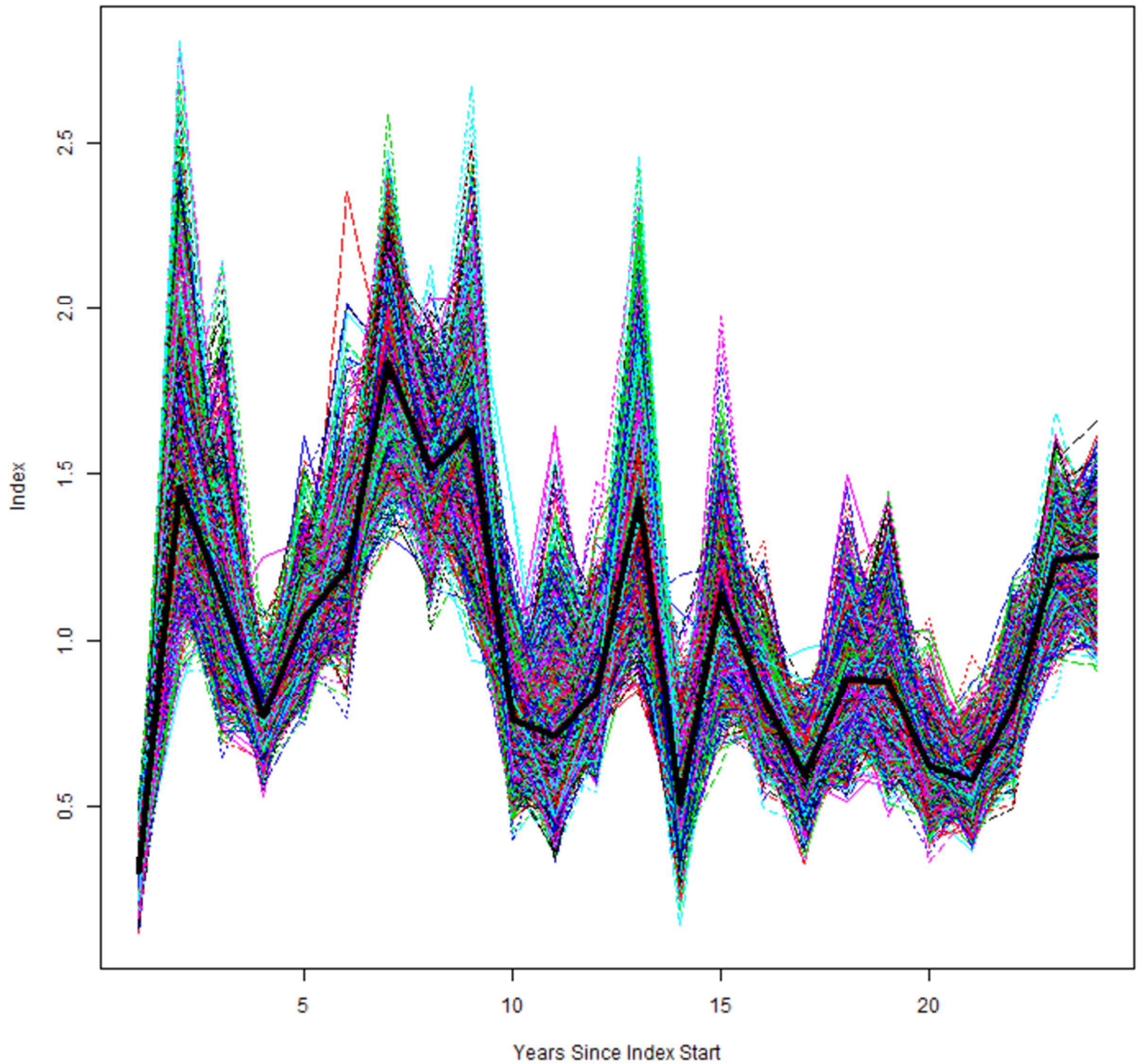

Figure 21. Plot of all individual bootstrap runs normalized annual relative abundance index. Superimposed (black line) is the predicted annual relative abundance index based on the observed catch data.

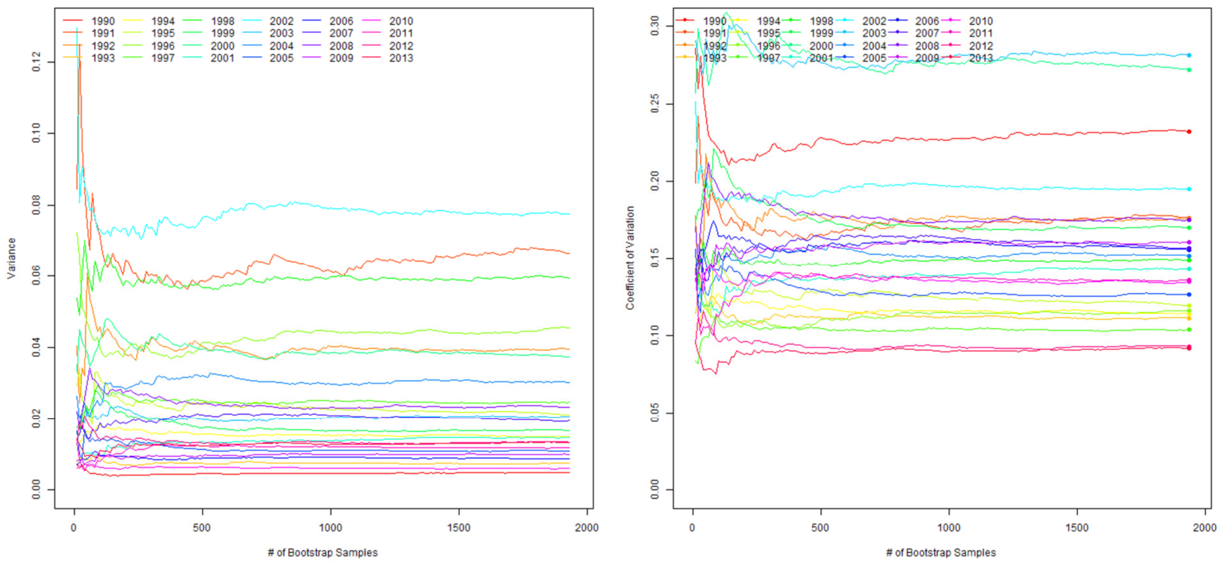

Figure 22. Bootstrap diagnostic plots used to determine if variance (left) and coefficient of variation (CV; right) estimates stabilized over the number of bootstrap iterations run.

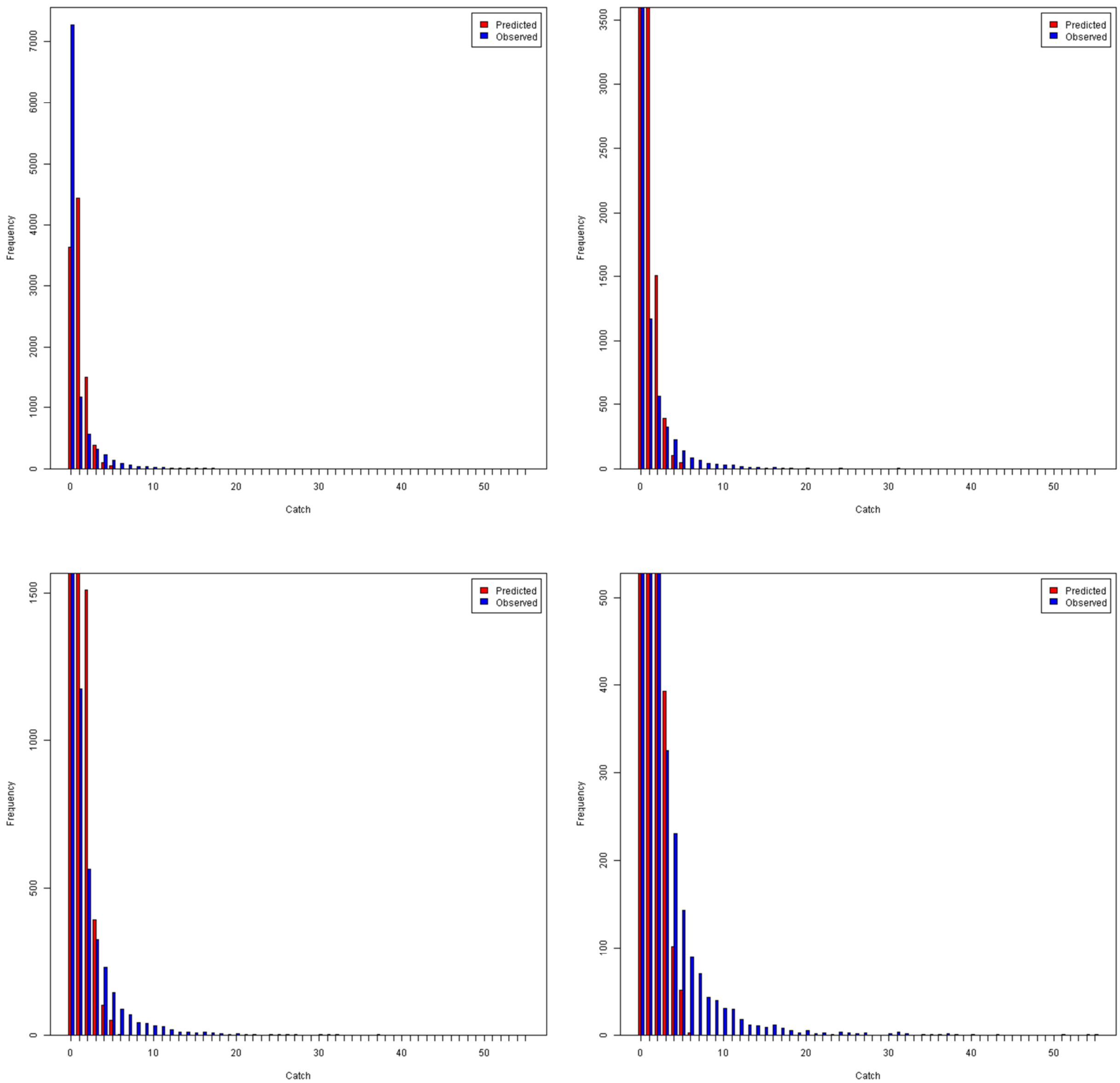

Figure 23. Frequency of traps observed (Observed) with a given catch of Red Snapper or predicted by the ZINB (Predicted). Plots represent the same data, with the y-axis truncated to better resolve low frequencies as one moves clockwise through the plots starting with the top left plot.

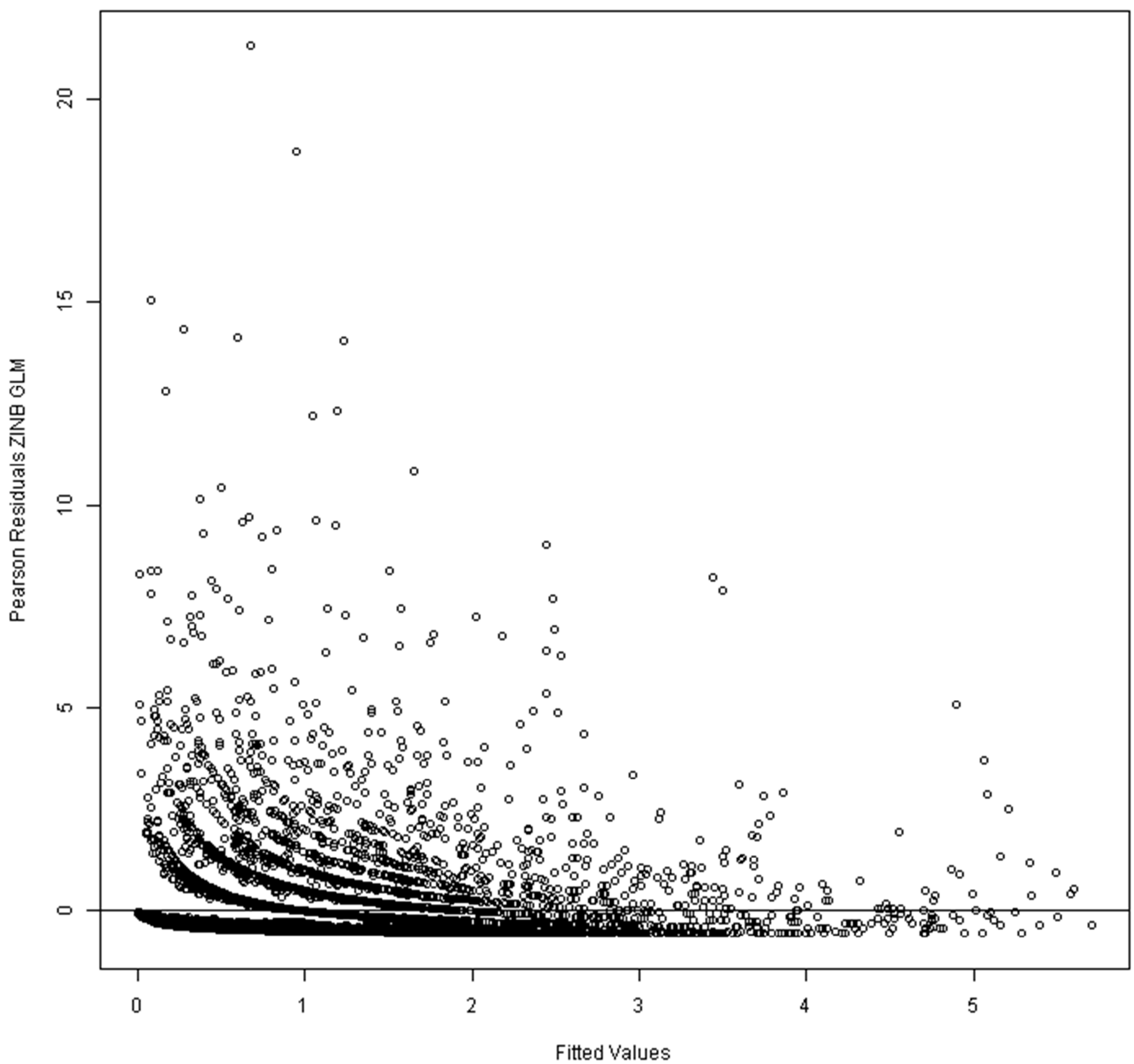

Figure 24. Pearson residuals versus fitted values for the final ZINB model.

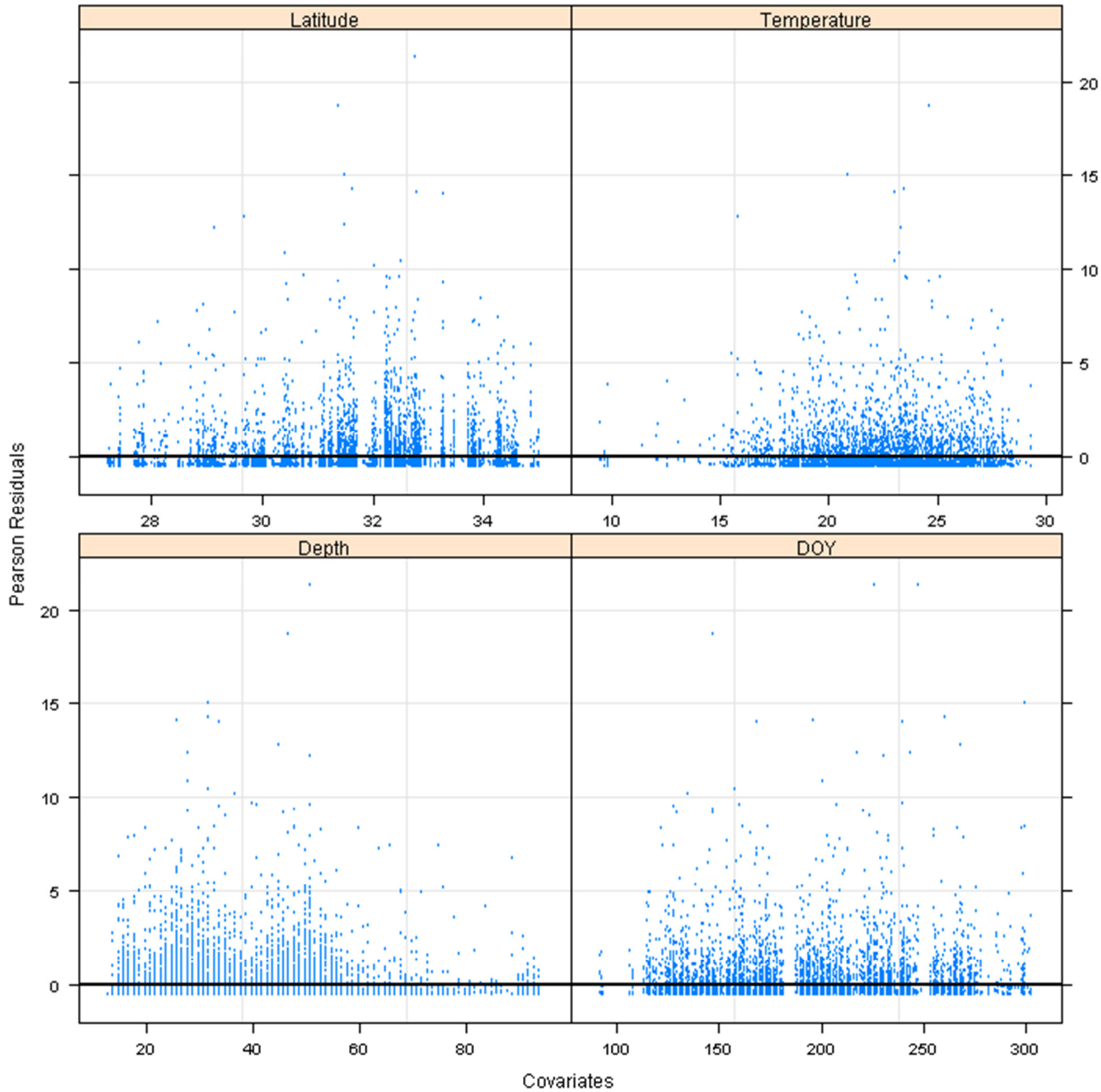

Figure 25. Pearson residuals versus covariates included in the final ZINB model.

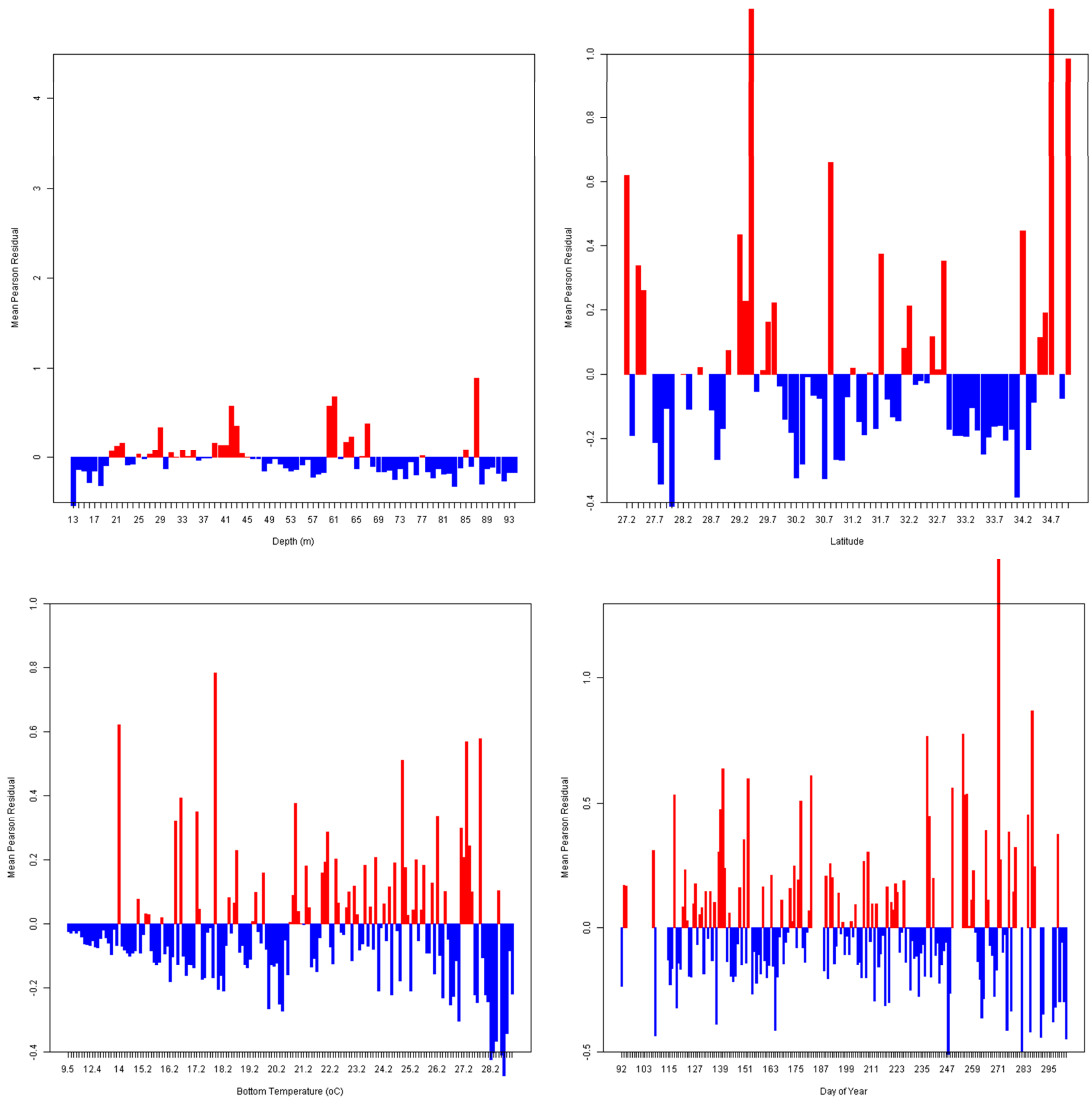

Figure 26. Mean Pearson residual versus included covariates for the final ZINB model.

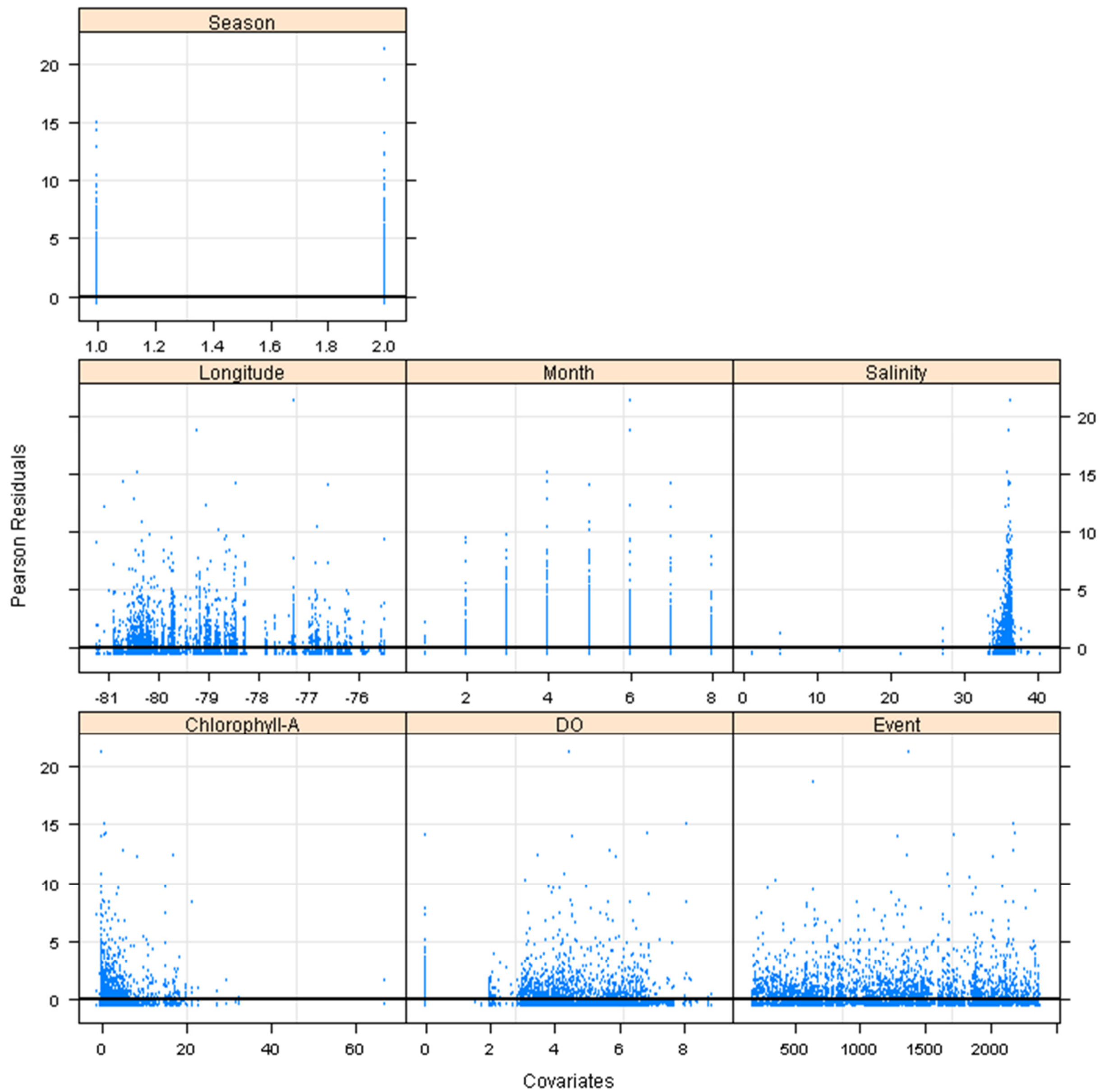

Figure 27. Pearson residuals versus covariates excluded from the final ZINB model.

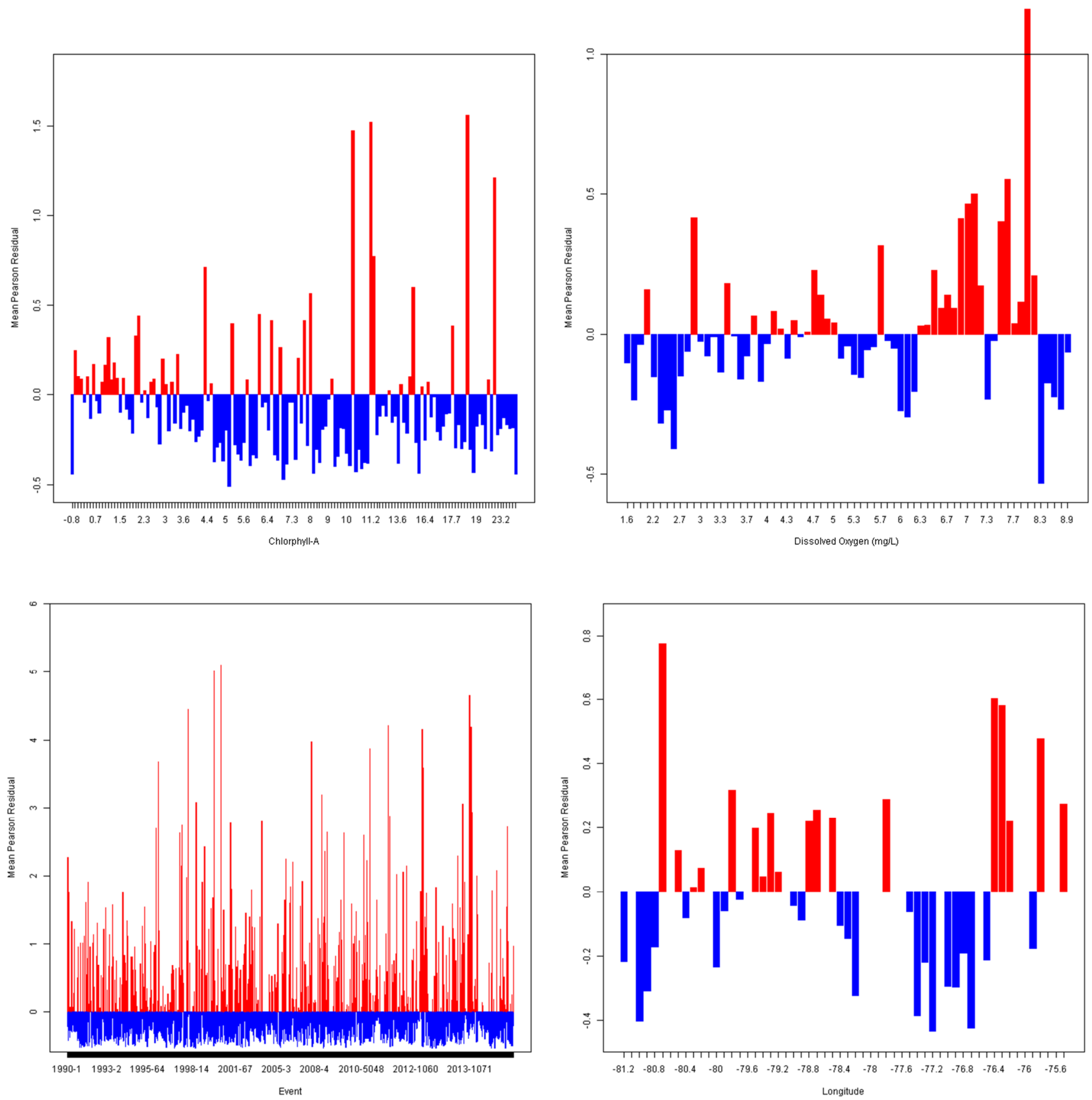

Figure 28. Mean Pearson residuals versus covariates excluded from the final ZINB model.

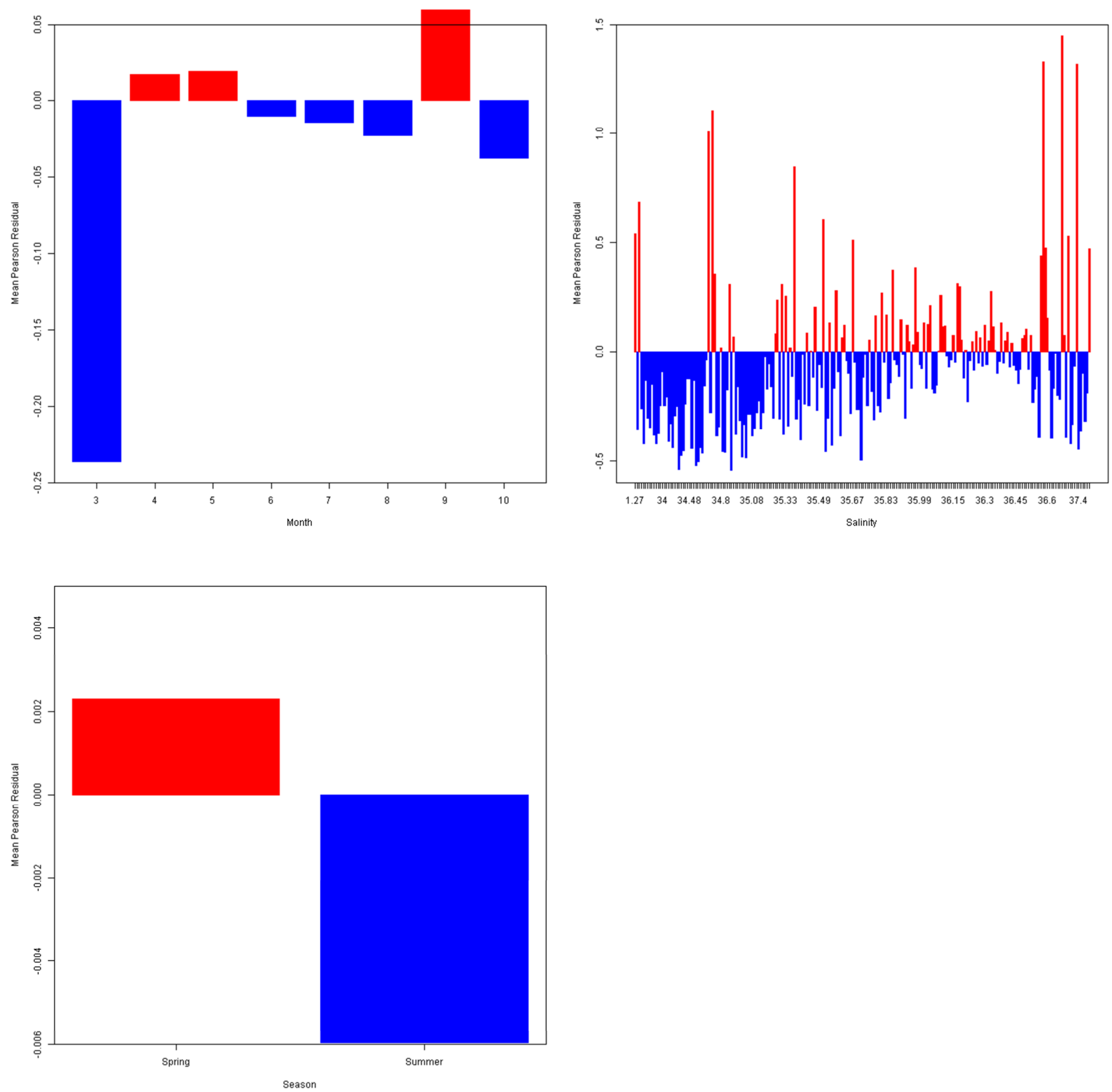

Figure 28 (cont). Mean Pearson residuals versus covariates excluded from the final ZINB model.

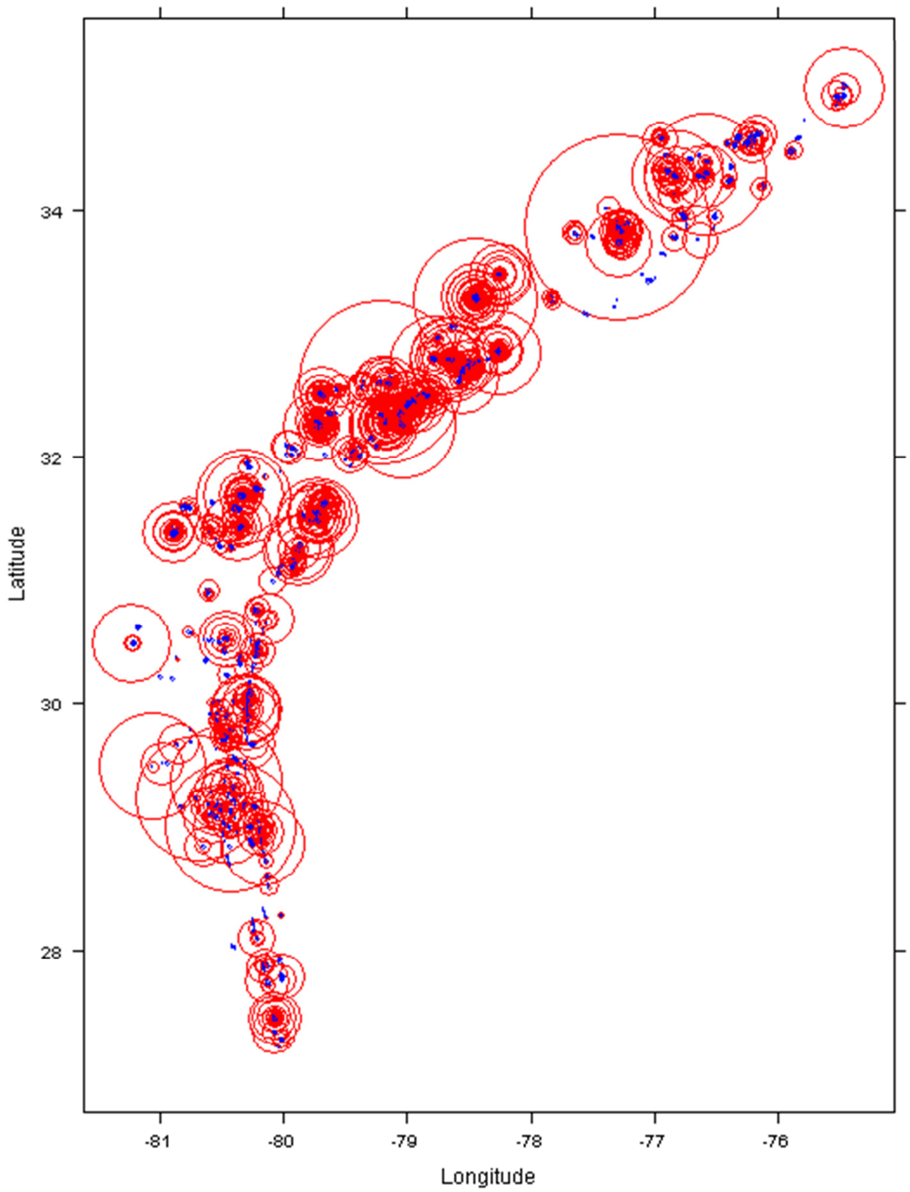

Figure 29. Spatial distribution of Pearson residuals. Red circles indicate positive Pearson residuals and blue circles represent negative Pearson residuals. Size of the circle is indicative of the magnitude of the residual with larger circles corresponding to larger Pearson residual values.

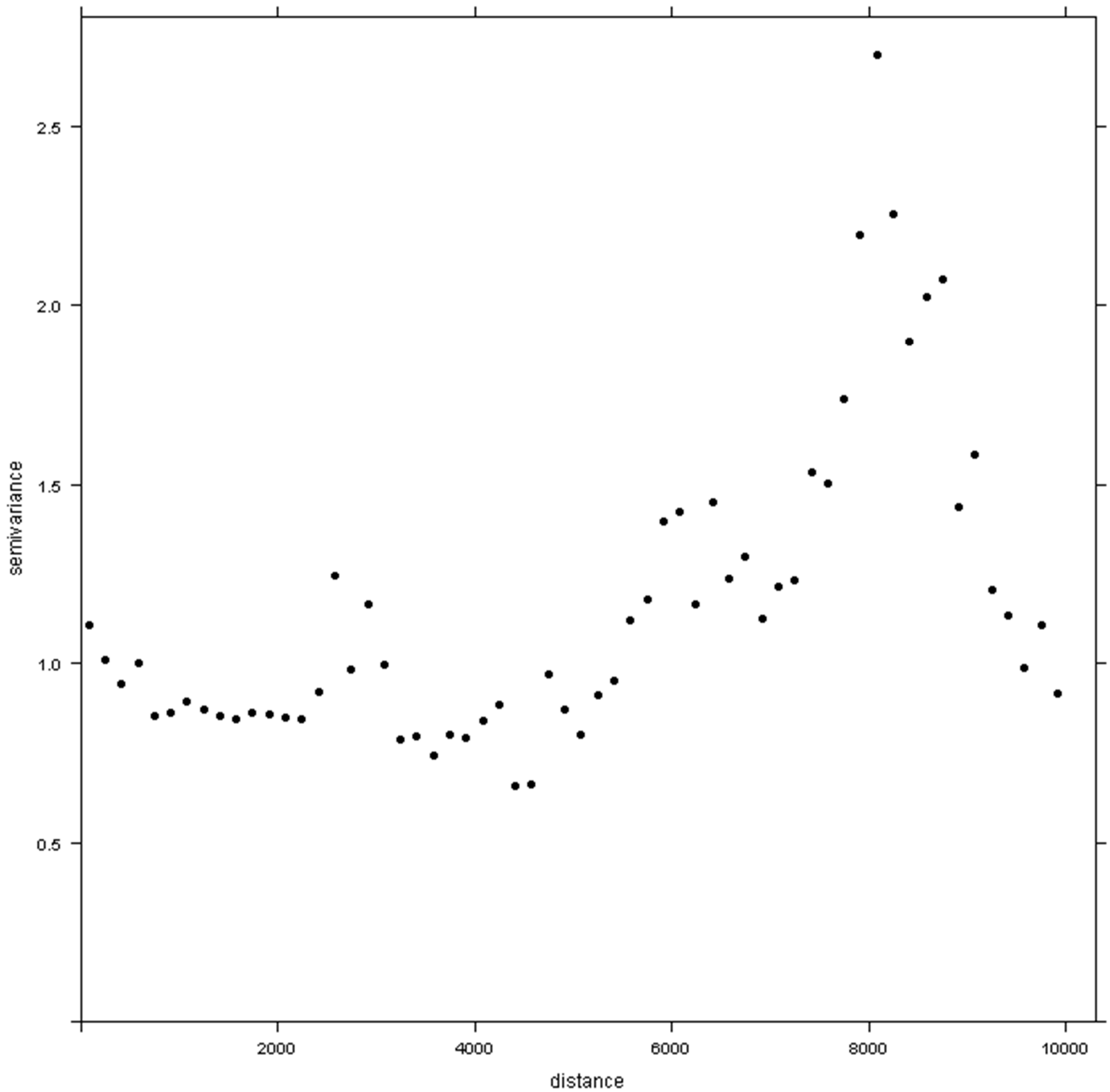

Figure 30. Sample variogram of Pearson residuals. The sample variogram is limited to 10,000 m (10 km).

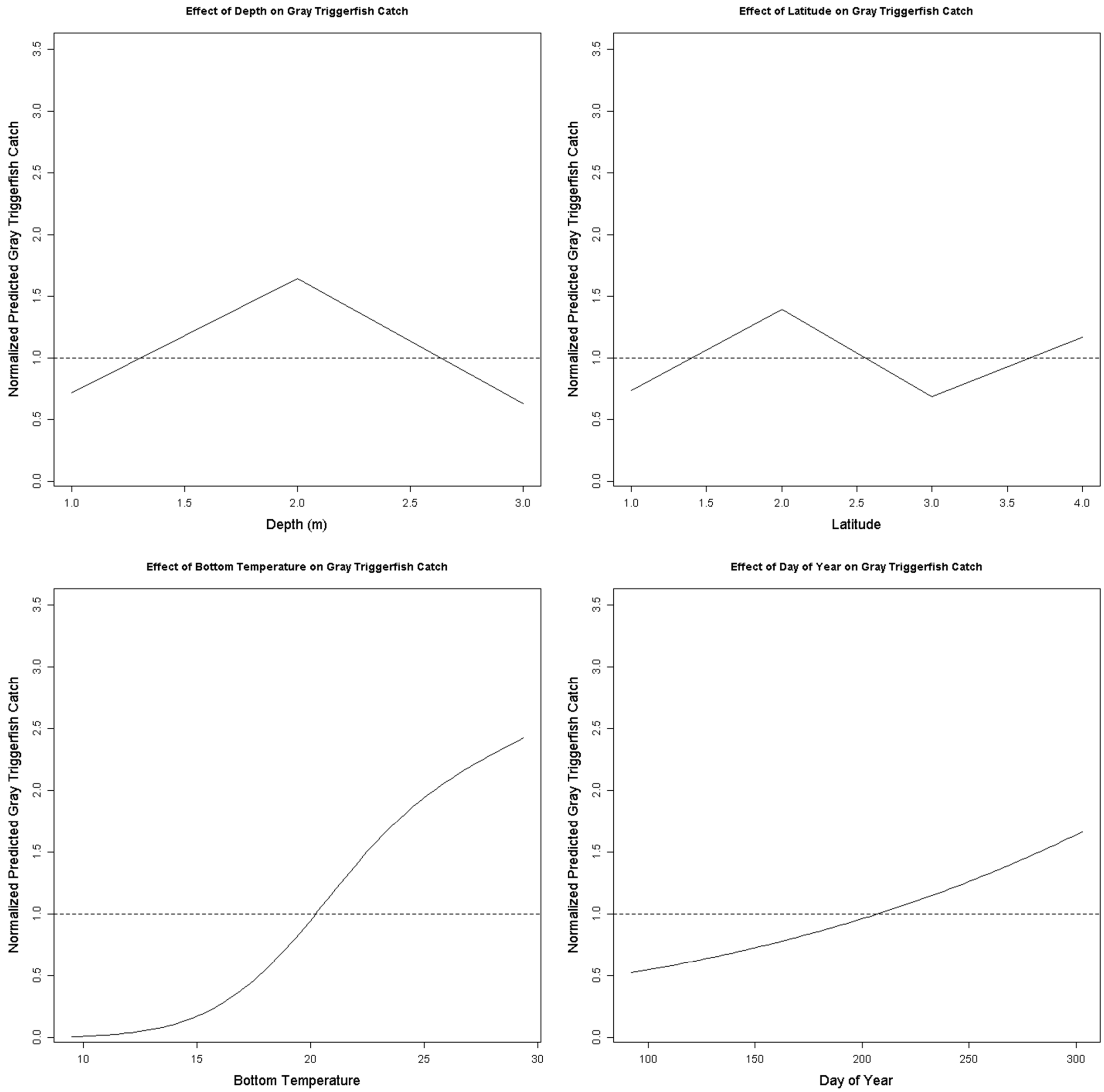

Figure 31. Covariate effects on predicted Gray Triggerfish catch.